CENTER FOR Children & Technology

Adventures in Supercomputing 1994 - 1995 Evaluation

Final Report

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Executive Summary

The goal of the Adventures in Supercomputing program is to cultivate the interests of diverse populations of high school students in mathematics, science, and computing. The AiS curriculum introduces students to the field of computational science, in which supercomputers are used to run simulations based on mathematical or physical models. Students engage in long term projects that require them to pose hypotheses, devise methods and procedures for solving problems, and draw on a wide array of resources including text and electronic sources, computer simulations, and human experts, to undertake their inquiries. With its emphasis on independent and original student research, the AiS curriculum dovetails effectively with current education reform efforts.1

- The 1994-1995 evaluation of the AiS program builds on an evaluation conducted during the 1993-1994 school year. For both years, the evaluation was designed to assess student learning as evidenced in final project presentations, and to systematically examine variations in learning based on a range of demographic and contextual data. Using performance-based assessment measures, students' project presentations were videotaped according to a standardized format. A subset (n=139) of students from five states were required to present their final projects to an audience of Department of Energy program staff, state site coordinators, and their teachers. Videotapes were scored using established performance assessment criteria.

Given key implementation conditions, central findings emerge:

- Mean scores for the videotaped sample of students rose between 1993-94 and 1994-95 on four of five dimensions, the fifth remaining stable.
- The AiS program is reaching a diverse group of students, ethnically and socio-economically, and is reaching many girls. Student sex, ethnicity and socioeconomic status are not indicative of achievement in AiS. However, boys are more likely than girls to bring previous programming experience to the course, and this factor favorably influences their chances for success in the program.

Teacher characteristics that are key to successful implementation of the AiS curriculum include:

- experience as an educator;
- familiarity with using technology in the classroom;
- experience with teaching through project-based work.

Consequently, supporting teachers in developing their fluency with classroom technologies and with project-based teaching are key to the continued expansion of the program. Additionally, the program needs to continue to focus on supporting teachers and students in the process of developing tractable and well-defined topics for computational investigation.

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1 National Center for Improving Science Education, 1991; NCTM Commission on Standards, 1989; Task Force on Educational Network Technology, 1993; U.S. Department of Education, 1994.

Introduction:[1] *Background on the Adventures in Supercomputing Program*

The Adventures in Supercomputing (AiS) program, funded by the U.S. Department of Energy, was initially established in Iowa, New Mexico, and Tennessee in 1992, with Ames Laboratory, Sandia National Laboratories — Albuquerque, and Oak Ridge National Laboratory hosting the program in their respective states. In 1993, the program was expanded to include sites in Alabama and Colorado, hosted by the University of Alabama at Huntsville and Colorado State University, respectively.

The goal of AiS is to cultivate the interests of diverse populations of high school students, particularly students of color, girls, and economically disadvantaged students, in science, mathematics, and computing. The AiS curriculum introduces students to the field of computational science, in which supercomputers are used to run simulations that form the basis of scientific experiments.

Over the last 20 years, computational science has emerged as a powerful method of analyzing a variety of problems in both basic and applied research, including product and process development, and many aspects of manufacturing. Computational scientists develop simulations that are based on mathematical or physical models that provide both qualitative and quantitative insights into many phenomena that are too complex to be dealt with by analytical methods and/or too expensive or too dangerous to study via material experiments. The availability of high performance computers, graphic workstations, and high speed networks, coupled with major advances in algorithms and software, have made it possible for computational simulations to replace more traditional laboratory investigations.

A computational scientist, using networking and visualization tools, works at the intersection of several disciplines: applied science or engineering, computer science, and mathematics. This multidisciplinary activity has enabled computational scientists to tackle a number of diverse phenomena, including:

- Numerical wind tunnel research. The use of computational techniques in this area has made experiments which would previously have been impossible to conduct in a real wind tunnel. For example, through computing and visualization, the flow over a planetary probe entering the atmosphere of Jupiter can be effectively simulated and researched.

- Computer crash testing of automobiles. Not only has this technique proven cost effective (real cars are not destroyed) it has resulted in more insight into crash dynamics than conventional crash testing with real cars has permitted.

- Pharmaceutical design. In simulated experiments researchers try to find molecules which will “fit” into active sites on a biologically-important substance. These molecules can then either activate or inhibit biological processes.

- Oil exploration and recovery. Seismic data is analyzed to locate potential sites for drilling. Optimal pumping strategies are determined for existing oil fields.

- Analysis of genetic data. This research includes the sequencing of the human genome, which if successful will be the foundation for curing many genetically-linked diseases.

Rationale for Program Development

The Department of Energy's efforts to introduce a computational science curriculum into high schools dovetails effectively with many of the educational reforms that are currently being proposed to support more engaged and substantial forms of student learning. The AiS curriculum supports students' involvement with real-world problem-solving activities. Students are expected to conduct extensive research for their projects, and they are asked to design and execute programs or simulations that will aid in solving problems. In addition, a major component of both AiS and the educational reform agenda is the introduction of technologies, principally computing and communications technologies, to improve teaching and to facilitate learning. The goals of the AiS program are consistent with national educational goals, in that they are geared to using the most up-to-date resources available to improve mathematics and science education for all students (Means, et al, 1993). The AiS program brings girls, students of color and economically disadvantaged students into contact with computational scientists and with the technology those scientists use to conduct their own complex inquiries and analyses.

With its emphasis on independent and original student research, the AiS program is in line with current educational reform efforts (National Center for Improving Science Education, 1991; NCTM Commission on Standards, 1989; Task Force on Educational Network Technology, 1993; U.S. Department of Education, 1994). During AiS class periods, students are likely to be working in small groups, or independently, on activities related to these goals. These kinds of classroom activities differ significantly from usual high school science or math classes. High school students typically spend much of their class time engaged in activities that stress delivery and retention of information, such as listening to teachers lecture, watching teachers work problems on the board, and taking tests (NSB, 1993).[2] AiS students, in contrast, spend their class time refining hypotheses, collecting data, developing methods for analysis, and synthesizing the results of their work. These activities, which create greatly increased opportunities for student discussion and involvement, are far more likely to lead to conceptual understanding of material and better developed problem-solving skills (NCTM, 1989).

The AiS course also offers an opportunity for female students, students of color and economically disadvantaged students who are less likely to enroll in advanced mathematics and science classes to engage in independent research, and to pursue novel problems of their own invention. In addition to being in line with educational reform agendas, this curricular approach has shown promise in narrowing gaps in student performance (Collins, et al, 1991; Linn, 1992). Research has found that when novel problem-solving and integration of conceptual and procedural knowledge is stressed in curriculum and assessment, performance gaps that persisted in traditional curricula and assessment techniques are eliminated (Linn, 1992; Wellesley College Center for Research on Women, 1992). Because the AiS curriculum supports students as they engage with diverse and complex fields of scientific inquiry, the program presents an opportunity to examine the efficacy of substantive investment in high quality, innovative science and mathematics instruction for all students.

Selection, Training and Resources

In order to be selected to participate in the AiS program, schools must submit an application. The applications are evaluated by selection committees in each state to determine which schools are the most qualified to carry out the program successfully and reach a significant number of women, students of color, and economically disadvantaged students. Typically, selected schools either have a large disadvantaged student population, or the applying teachers propose specific means to attract such students into AiS classes.

Once selected, teachers receive extensive training in how to use computational tools and in how to design and implement a program that will work effectively in their local school community. Teachers attend a summer institute for training and participate in fall and spring AiS workshops. During the Summer Institutes, teachers receive instruction in how to present introductory concepts in high performance computing to their students. They learn how to use scientific visualization software, and they experiment with the use of computational tools in modeling scientific problems. Teachers also develop a course outline and timeline that will work in their school environment.

The Summer Institutes include hands-on experience in the use of a range of technological tools: FORTRAN and parallel programming techniques, UNIX commands, pico (an editor), scientific visualization software, Macintosh familiarization, ClarisWorks (integrated word-processing, spreadsheet, and database software), and networking. Presentations are also made by DOE staff and visiting education and scientific professionals.

During the fall and spring workshops teachers receive follow-up instruction on technical applications. They also have the opportunity to discuss with colleagues the ways in which they are implementing AiS in their local schools and to explore strategies for resolving challenges they may be encountering, such as finding mentors and selecting projects.

Throughout the school year teachers and students have access to state-of-the-art high-performance computers, software, and networks, and expertise in computational science. All five states provide access to nCUBE parallel supercomputers through a UNIX workstation front end. AiS participants also have access to the National Education Supercomputer located at Lawrence Livermore National Laboratory, and are able to access all of the resources available on the Internet. Scientists and engineers working in various fields of computational science, applied mathematics, parallel computing, and computer science serve as mentors for students participating in the program.

AiS Curriculum

Because the program is targeted at students who are least likely to be attracted to scientific, mathematical, and computational fields, the AiS program does not require that students have prior programming experience. The only prerequisite for student involvement in AiS is Algebra I. As a result, a substantial part of the year-long curriculum is devoted to teaching students FORTRAN and parallel programming techniques. By the end of the school year students are expected to be able to apply programming solutions to scientific problems.

All participating AiS teachers are given a sample supercomputing course outline which they use as a guide in implementing the program in their schools. Teachers are encouraged to duplicate and adapt the material to suit their particular situations. In most schools, the AiS curriculum runs for an entire year. During the first several weeks of the course students are introduced to the field of computational science and the purpose of supercomputers. During the first half of the course they also begin to learn the essentials of FORTRAN. By mid-year they are expected to have identified and begun to develop their project topics; during the second half of the course students continue to conduct research into their topic area, consult with mentors on the design and execution of the programs they are writing and the computational tools they are using, and prepare for their final project presentations.

Evaluation Design

This evaluation study builds on the evaluation study conducted by Education Development Center during the 1993-1994 school year. The 1994-1995 evaluation of Adventures in Supercomputing was designed to expand upon that evaluation by working with a greater number of schools, while keeping the overall research design essentially the same. Because teachers' knowledge of and comfort level with any educational innovation is key to its success (Brunner, 1992; Hawkins, 1993; Sheingold & Hadley, 1990), a decision was made in the 1993-1994 evaluation to assess student learning in only those courses taught by teachers who were beginning their second year of involvement in the AiS program. As a result, the evaluation was limited to students of the 1992-93 cohort of teachers in three states: Iowa, Tennessee, and New Mexico. The 1994-1995 evaluation focused on second-year AiS schools in Alabama (5 schools) and Colorado (7 schools), and also included eight third-year AiS schools in Iowa (2 schools), New Mexico (three schools) and Tennessee (three schools). This selection allowed us to pursue two goals: to establish a uniform body of evaluation data collected from second-year AiS schools in all five participating AiS states; and to continue to evaluate the development of the program in schools undertaking their third year in AiS.

The educational goals and objectives that are central to student learning in the AiS curriculum emphasize the acquisition of thinking and problem-solving skills. Students engage in long term projects that require them to pose hypotheses, devise methods and procedures for solving problems, and draw on a wide array of resources including text and electronic sources, computer simulations, and human experts, to undertake their inquiries. The inquiry-based and analytical skills that students are asked to develop in the AiS program are not effectively measured by traditional paper and pencil tests. They require a form of assessment that enables students to demonstrate their understanding of the complexity of the task they have undertaken, that moves beyond the recall of facts and concepts toward demonstration and documentation of the processes and procedures that are used to solve particular problems. This type of assessment, known as "authentic," records and judges the qualities of actual performances, rather than inferring an ability to perform from indirect and decontextualized measures such as multiple choice tests.

A particular authentic assessment technique known as performance assessment (Hawkins, et al, 1993; Herman, et al, 1992; Linn, 1993; Rudner & Boston, 1994; Wiggins, 1990) was selected for the purposes of the AiS evaluation. This type of assessment focuses on student projects as comprehensive demonstrations of their skills and knowledge. Student projects are central to the AiS curriculum; they require a broad range of competencies, are often interdisciplinary in focus, and require student initiative and creativity. All students in the AiS program are expected to complete projects and demonstrate their proficiencies by presenting their work at a state Expo.

In accordance with the standard techniques of performance assessment (Frederiksen, 1994a; Frederiksen 1994b; Hawkins, et al, 1993; Herman, et al, 1992), the evaluation was structured to document student projects by videotaping student groups as they presented their project to a group of peers and experts. Group presentations give students the opportunity to explain in depth both the content and the process of their year's work, and allows for questioning by audience members. Because the questions and criteria deemed to be important (i.e., consistent with program goals) are known to the students, the teachers, and the program evaluators, this type of presentation gives the maximum opportunity for full and complete demonstration and documentation of student knowledge. Videotaping presentations allows for in-depth analysis of students' performances by coders who are familiar with the curriculum, and are trained in the interpretation and application of the coding system. Once collected, videotape documents are coded according to a set of student learning criteria and clustered to determine types of student achievement that result from participation in the AiS program.

Previous research on technology innovations indicates that factors such as teachers' prior experience with technology, the number of years teachers have been teaching, the number of technology-using teachers in a school, the school's overall investment in technology resources, and the ways in which teachers choose to interpret and implement a new curriculum make a critical difference in the effectiveness of technology-rich educational programs (Becker, 1992; Brunner, 1992; Sheingold & Hadley, 1990). Therefore, in order to better understand variations in student learning established through the analysis of project presentations, three other types of data were collected. This data includes i) demographic information that characterizes AiS teachers, students, and schools[3]; ii) additional student learning data (learning process data) that explores the development and refinement of students' ideas and questions; and iii) contextual data that investigates the circumstances in which the AiS curriculum is being implemented.

1) Demographic data.
   a) Student demographic data was collected to determine the number of male and female students participating in AiS; their race, socio-economic status, grade level, and age; their prior experience with computers; their math and science background; their attitudes toward math, science and AiS classes; and prior involvement in AiS.
   b) Teacher demographic data was collected to investigate variables such as years of teaching experience; subject areas and grade levels taught; experience using computers for instructional purposes; and the availability of computers and modems at home.
   c) School demographic data was collected on a range of variables, including size of school; percentage of students who are below the poverty line; number of students of color enrolled; percentage of graduates that go on to college; amount of computer-based technology in the school; and the number of years teachers in the school have been using computers for instructional purposes.

2) Contextual data.
   a) School visits. Through visits to a sub-sample of AiS schools (16 schools) data was collected that investigated the ways that the AiS curriculum is implemented in different sites. During each visit the following information was collected: AiS classes were observed; teachers were questioned about the ways in which they were implementing the AiS curriculum; and students were questioned about their interest in AiS, the development of their project ideas, and their use of resources, such as AiS mentors and the Internet.
   b) Teacher reports of program implementation. Two sets of contextual questions were asked in the teacher survey: how teachers were implementing the AiS curriculum (were they team-teaching, did they have a dedicated AiS class, etc.), and their experiences of the challenges and benefits of teaching AiS. These questions were developed based on responses collected in teacher interviews conducted during the 1993-1994 evaluation study. These questions covered issues including their

objectives for their AiS classes and their feelings about the most exciting aspects of the AiS course for themselves and for their students.

3) Learning process data.
   a) Electronic journals were collected on a monthly basis, querying students on topics including project topic selection, experience with mentors, problems encountered, and the modification and refinement of project ideas and questions.

The learning process data and the demographic data were analyzed to determine those variables that correlated significantly with student project presentation data. Contextual data was used as an interpretive framework to elaborate on the meaning of those variables found to be significant, and to help identify significant variables which might be confounded.

The report is organized into eight sections. The first three sections present findings from the demographic, contextual, and student learning data. Implications of findings are discussed in each section. The fourth section presents findings from the performance assessment of students project presentations. The fifth section presents those elements of the demographic and learning process data which significantly correlated with findings from student presentations. A sixth section compares this year's evaluation findings to findings from the 1993-1994 study. A seventh section presents conclusions, and an eighth presents recommendations based on findings from two years of program evaluation.

Demographic Data: *Student Demographics*

Method

Student demographics were solicited from all students participating in the AiS program. Data reported here reflect responses from all responding students *except* students in the AiS junior high schools. Data was collected from 1303 high school AiS students, reflecting 67 classes in 59 schools. Removing the 214 students who dropped the class leaves a final number of 1089 students who completed the AiS program. 954 students were in the program for the entire year and 135 students started in the January semester (January starts were only in Colorado, Iowa and New Mexico). Nearly half of the students who dropped the class were 12th graders (103 students). Specific Ns fluctuate slightly for individual items, and will be noted in each case.

Results

Sex and ethnicity. The AiS student population is 39.2% female and 60.8% male (n=1055) (see Figure 1). Three states have more male students: Colorado — 33.7% female/66.3% male; Iowa- 30.9% female/ 69.1% male; and New Mexico — 31.4% female/68.6% male. Tennessee is just about even with 49.3% female and 50.7% male students, and Alabama is drawing a majority of girls – their student population is 60.7% female, and 39.3% male (see Figure 2).

Figure 3 illustrates the ethnic distribution of the AiS students (n=1002). 3.4% of AiS students are Native American, 3.5% are of Asian or Pacific Island descent, 13.6% are Hispanic, 8.4% are African American and 71.2% are white. This overall breakdown represents two distinct patterns of ethnic makeup. Iowa and Tennessee share one profile: their student populations are over 80 % white (92.9% in Iowa and 81.8% in Tennessee), include some African-American students (3.4 % in Iowa and 12% in Tennessee) and a very small number of students from other ethnic categories. Alabama, Colorado, and New Mexico share a different profile: their student populations are around 50% white

Figure 1
Composition of AiS Students by Sex
(n=1055)

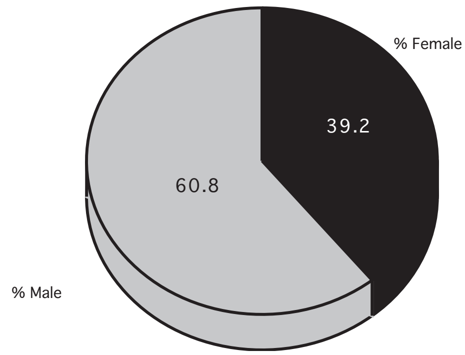


Figure 2
Comparison of AiS Student Sex by State

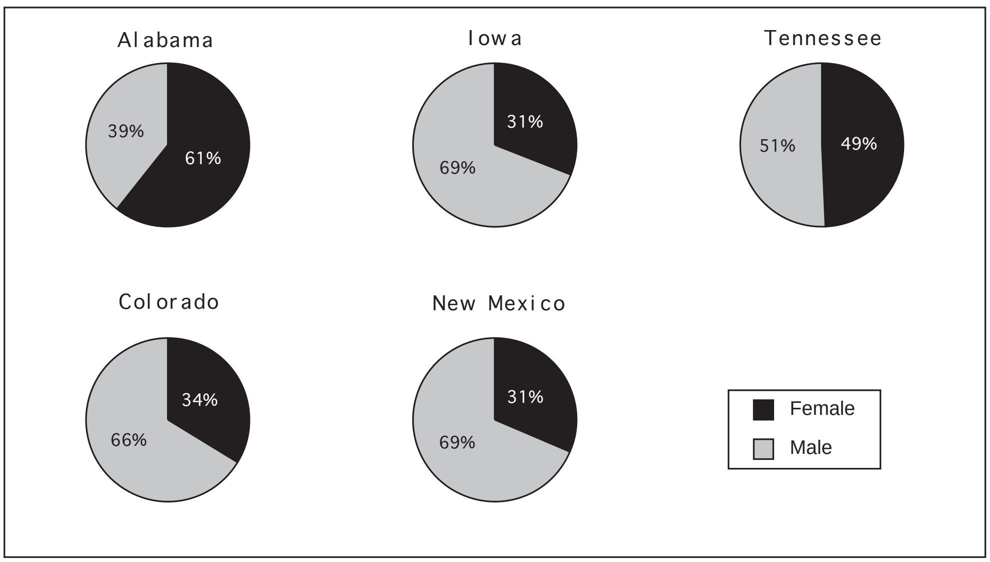
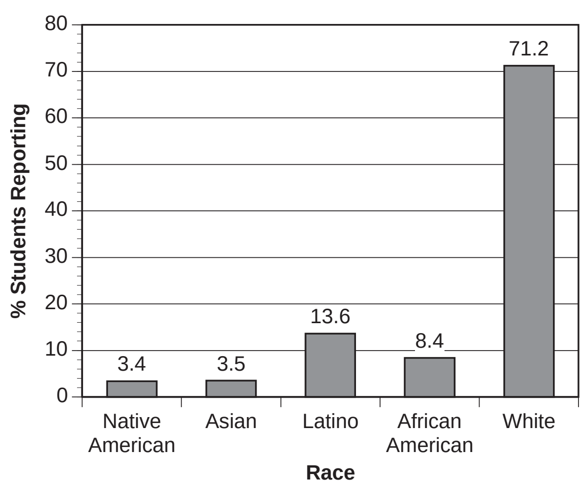


Figure 3
Composition of AiS Students by Race
(n=1002)



(Alabama: 50.5 %; Colorado: 50%; New Mexico: 53.4%). In Alabama the next largest group is the African American students (36.6%) while Colorado and New Mexico have substantial numbers of Hispanic students (39.6% and 34.4% respectively). Colorado also has a significant population of Asian students (8.3%). Native American students comprised the largest contingent in New Mexico with 6.1% of that state's AiS population. In Alabama, Native American students were 5.9% of the total.

In comparison to the racial and ethnic breakdowns for the general population in each state, all five state AiS programs have made significant efforts to include all sectors of their populations. Alabama has attracted more students from minority populations than are represented in the state's overall population. At 36.6% African American, Alabama's AiS program is substantially above the state population's share of 25% African American. The same, or similar, ratios hold true for Native American, Asian/ Pacific Islanders and Hispanic. Colorado has been successful in including Hispanic students — the AiS population is 39.6% Hispanic to the overall population's 12.9% share, and Asian students — 8.3% in AiS and 1.7% overall. They have been less successful in attracting African American students — 1% in AiS to 3.9% overall. Iowa, which is overwhelmingly white (95.9%), has also boosted the number of African American students (3.4% in AiS to 1.7% overall) and Asian and Native American students (1.9%, 1.5% respectively in AiS to 0.9% and .2% overall). New Mexico's program numbers are slightly below the state's overall population: 34.4% Hispanic students in AiS to the state's overall 38.2%; 6.1% Native American students to the their 8.5% share in the state. Tennessee is also reporting equivalent shares as the overall population, except for Native American students who are 2.5% of AiS and .2% overall. African American students make up 12% of AiS classes, while African Americans are 16% of the state population (see Figure 4).

Grade level and age. Juniors and seniors make up almost three-quarters of the AiS student population (see Figure 5). Seniors are nearly half the entire population at 42.2 % of AiS students; 31% are in eleventh grade. 19.8% are in tenth grade, another 5.7% are in the ninth grade and the remaining 1% are seventh and eighth graders (only four of whom are seventh graders). These seventh through ninth graders are participating in high school AiS programs in schools which serve kindergarten through twelfth grade, or seventh through twelfth grade. 11th and 12th graders are most numerous in Alabama, where they account for 90.5% of the total student population. New Mexico and Tennessee mirror the overall ratio of lower to upper grades in high school of 1:2 (27.6% 9th-10th/ 72.4%, 11th — 12th, and 28.2%/71.8% respectively). Iowa, and to a minor extent, Colorado both have seventh and eighth grade students. Colorado is 79.6% junior and senior students with 20% in the lower three grades. Iowa has 68.1% in the upper classes, 27.6% in 10th and 9th grades and 3.2% in seventh and eighth.

The mean age of AiS students is 16.3 (with a deviation of 1.1 years, and n=1036) (see Figure 6). There is no significant difference in mean age between boys and girls in the AiS program. 16-year-olds and 17-year-olds are predominant, accounting for 67.1% of the total group (27.9 % and 39.2% respectively). 16.8% are 15 years old, and 5% are fourteen or younger (only 9 students are under fourteen years old). 10.3 % of AiS students are 18 years old, and .8% (eight students) are nineteen years old.

Socio-economic status. Data was collected on AiS students this year that allowed us to extrapolate their socioeconomic status. Students were queried on the two factors that have been found to be the most reliable indirect indicators of income (Zill & Nord, 1994): their mothers' and fathers' level of education, and the type of employment they hold. This type of self-reported data can only provide a general indicator since it

Figure 4
Comparison of AiS Student Race by State

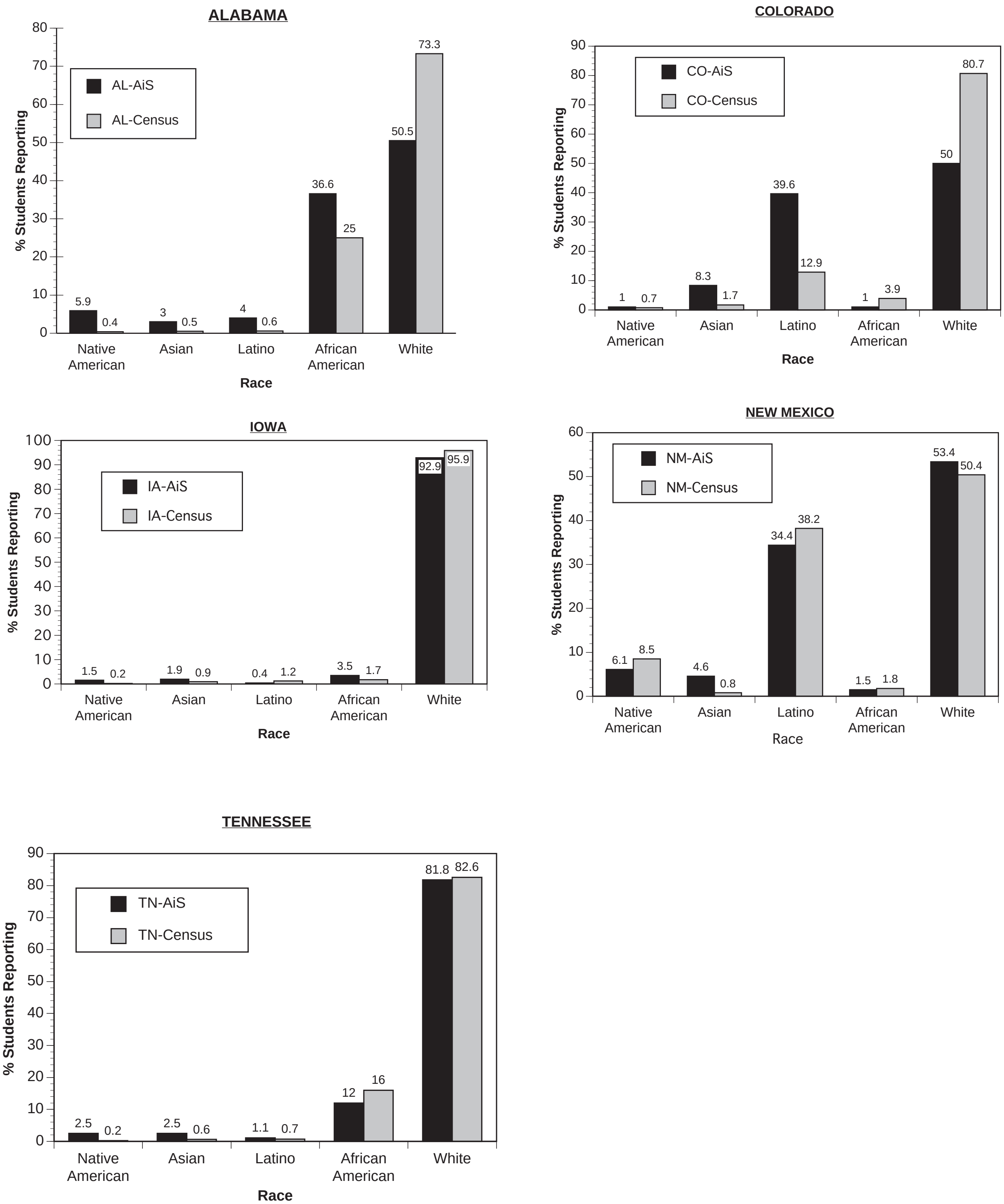


Figure 5
Composition of AiS Students by Grade
(n=1191)

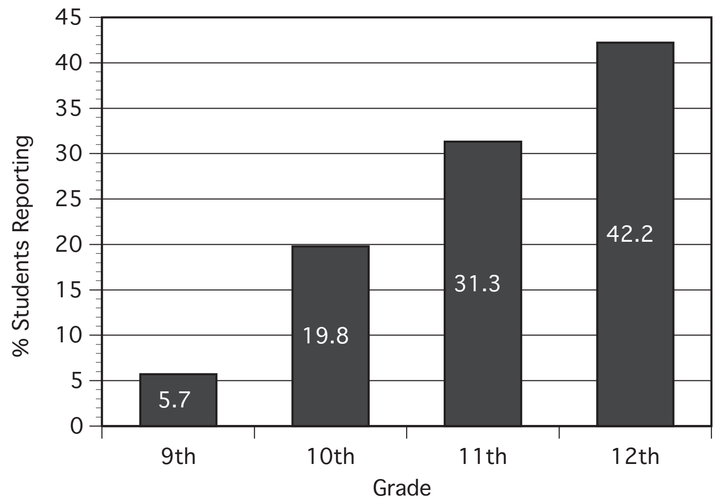


Figure 6
Composition of AiS Students by Age
(n=1196)

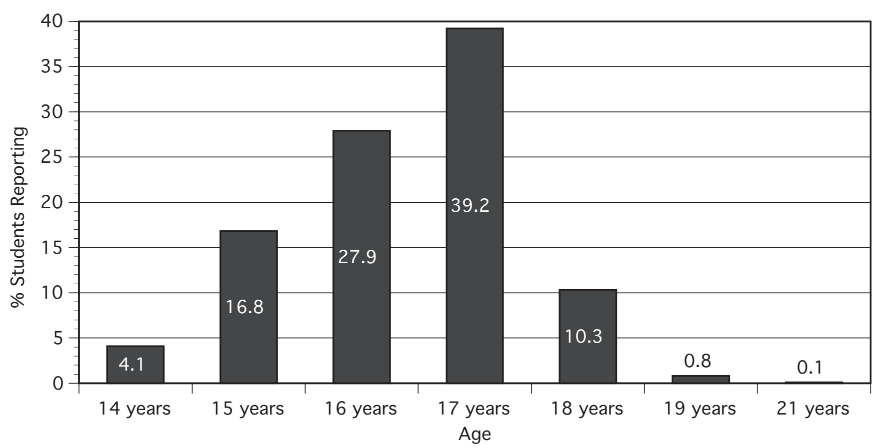
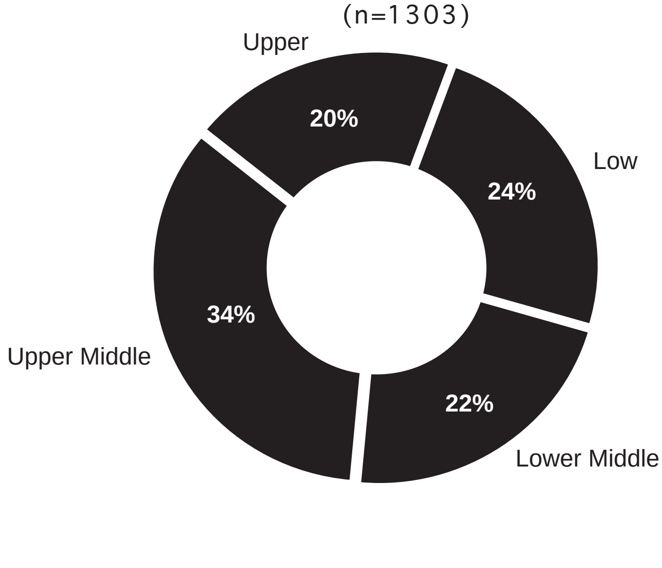


Figure 7
Composition of AiS Students by Socioeconomic Status
(n=1303)



relies on both the students honesty in reporting sensitive information and on their understanding of their parents' education and employment categories. Each of these measures was cross referenced with separate scales developed from the US census data and ranked according to mean income levels associated with the respective factors. The rank scores for each parent were then combined to create a continuum indicator of socioeconomic status. Students were then broken up into four categories, reflecting increasing family income and increases in parental education attainment. According to this schema, 23.9% falls into the low category, in which neither parent has gone beyond a high school education, and parents are employed in service, labor, or craft-related jobs. 21.9% is lower-middle: in this category most parents have completed high school and a few parents have attended college — this group of parents has a diverse range of jobs. 34.4% of the AiS student body falls into the upper-middle socioeconomic category: in this category both parents have some college education or have completed college, and parents have managerial jobs, are proprietors or are professionals. 19.7% are in the upper category — in this category all parents have at least some college education, many have graduate degrees, and almost all parents are engaged in professional occupations (see Figure 7).

Previous participation in AiS. 16% of students in this year's AiS program have previously been involved in AiS (n=170). All but 26 of these students had participated in a dedicated AiS class, while the others had participated in a club or non-credit experience. 96 of these students took projects to an Expo last year (56.5%). 67.6 % of these second-year AiS students are male, and 32.4 % are female.

Experience with and access to technology. More than half of the students participating in AiS have access to computers at home (57.7%) (n=1031). Two-thirds of these students with computers at home are boys (62.9%), and one-third (33.6%) are girls. Of these students with computers at home, 51.4% have modems as well. Of those boys with computers at home, 57.9% have modems, while 38.3% of the girls with computers at home have modems (see Figure 8).

AiS students use a range of computer applications on a regular basis (n=1014; see Figure 9).[4] Word processors, games, painting/drawing programs, spreadsheets, and databases were all reported by over half the students as kinds of applications that they use frequently (these were reported by 94.3%, 87.1%, 76.3%, 63.4%, and 50.1% of students, respectively). A higher proportion of boys than girls reported familiarity with each type of software, with the exception of word processors. An almost equal number of boys and girls reported familiarity with word processors. Desktop publishing programs, games, CAD software, databases, spreadsheets and painting programs were all listed as "programs I am familiar with" by about 8 % more of the boys than of the girls (i.e., 54.7% of boys included spreadsheets, and 42.9% of girls included them).

52% of students reported knowing at least one programming language other than FORTRAN (n=1089) (see Figure 10).[5] This includes 57.9% of the male AiS student population and 43% of the female AiS student population. 42% of students reported knowing BASIC. About 11.6% reported knowing PASCAL and 10.4% LOGO, and 6% reported knowing C or C++. 5% reported that they knew some other programming language, such as COBOL.

Discrepancies between boys' and girls' knowledge of programming were similar to differences in their experiences with computer applications. A larger proportion of the boys reported knowing each programming language. The largest difference occurred for BASIC: 46.6% of the boys and 32.4% of the girls reported that they knew this language. There was a 7% discrepancy in knowledge of C or C++ (8.7% of boys and 1.7% of girls); a 4.8% discrepancy for LOGO (12.3% of boys and 7.5% of girls); and a 2.4% discrepancy for PASCAL.

Figure 8
AiS students with computers and modems at home
(n=901)

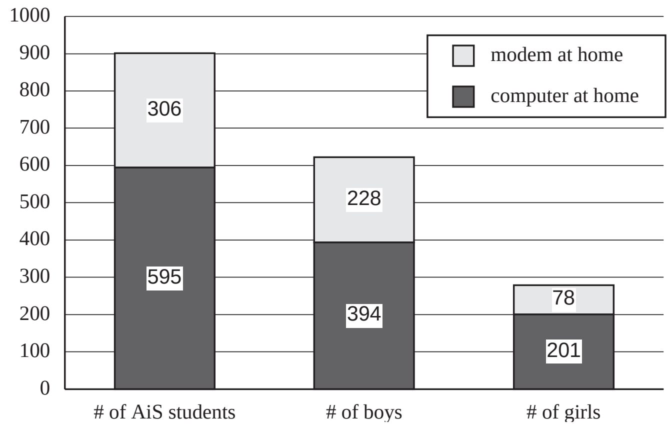


Figure 9
Types of Computer Applications Students Know How to Use,
Overall and by Sex
(n=1014)

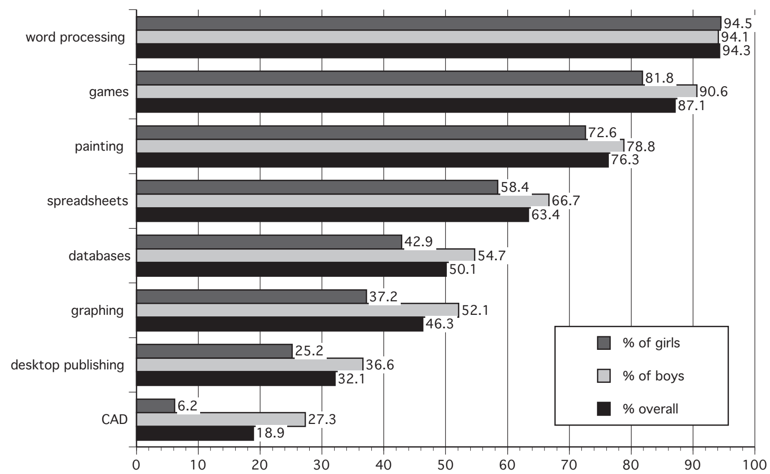
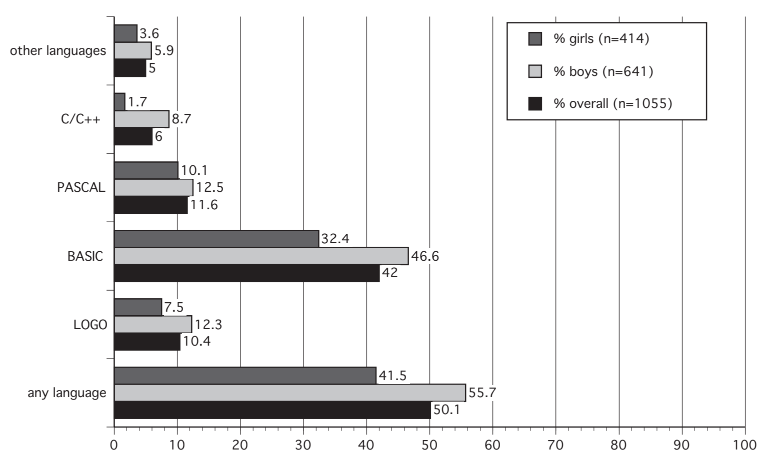


Figure 10
Programming Languages AiS Students Know,
Overall and By Sex
(n=1055)



When asked how often they used computers for their schoolwork during the last school year, nearly a quarter of the students reported using computers every day, and a quarter reported using them only a few times a year. 21.4% and 16.9%, respectively, reported using computers two or three times a week or only two or three times a month; and 12.5% reported using them about once a week. Girls reported using computers slightly less frequently than boys: 54% of girls said they use computers for their schoolwork at least once a week, compared to 60% of boys, and 29% of girls reported using them only a few times a year, compared to 22.6% of boys.

Mathematics and science backgrounds. See Figures 11-16 for a summary of AiS students' reports of courses taken in math and science (note that these reports do not include courses being taken concurrently with this year's AiS program) (n=1014).[6]

98.2 % of AiS students have taken algebra I, the course considered to be the prerequisite for enrollment in the class. More than half the students have also taken algebra II and/or geometry (61.9% and 73.5%, respectively). 26% have taken trigonometry, while smaller numbers have taken pre-calculus, calculus, AP calculus, statistics or remedial math (9.9%, 2.2%, 2%, 3.6%, and 3%, respectively).

The only science subjects that a majority of AiS students reported having studied was biology (85.3% in biology and 16.6% in AP biology) (n=785). 53.3% have taken chemistry (7.9% as an AP class); and 20.9% have had physics (3.9% have taken AP). A small number of students have taken geology, astronomy or engineering (5.6%, 4.5% and 1% respectively).

National statistics on course-taking patterns focus on courses students have taken by high school graduation (NCES, 1993). Consequently, it is most appropriate to compare only the twelfth graders in the AiS program to these national figures.[7] Figures 11a and 12a present comparisons of mathematics and science courses taken by twelfth graders in AiS and by high school graduates nationally. The comparison between the AiS seniors and high school graduates nationally is very different for math and science. AiS students are more likely to have taken all kinds of math courses, other than remedial courses and calculus, than is typical for high school graduates nationally (note that this does not include courses the AiS students are taking this year during the twelfth grade). However, AiS twelfth graders' patterns of science enrollment looks similar to national norms for physics and biology. These students are also more likely to have taken chemistry than high school graduates nationally (68% compared to 50%), and are less likely to have taken geology (5% compared to 25%).

More girls than boys have taken Algebra II or Geometry before enrolling in AiS (63.9% of girls and 60.5% of boys for Algebra II; 76.5% of girls and 71.5% of boys for Geometry). Previous experience with other math courses is not significantly different for boys and girls. More boys than girls have taken physics before enrolling in AiS (25.9% of boys, 13.6% of girls). Girls reported taking AP biology and chemistry more often than boys, but only by very small margins (margins of .2% and 1.9% respectively). When reporting other previous science classes, boys report taking more courses than girls, but the difference is minimal (margins range from 1.2% to 5%). Figures 15 and 16 review state trends in math and science backgrounds for AiS students.

Student attitudes toward math, science and AiS. Students were asked a series of questions about their feelings about math and science classes at the beginning and end of the school year. Questions about their attitudes about AiS, based on NAEP measures (Kahle, Matyas, & Cho, 1985; NAEP, 1979) were added to the year-end survey. Students were asked how often they felt curious, stupid, confident, or successful in math, science and AiS classes; how often they liked to go to these classes; and how often they

Figure 11
Mathematics Classes Taken by AiS Students
(n=1000)

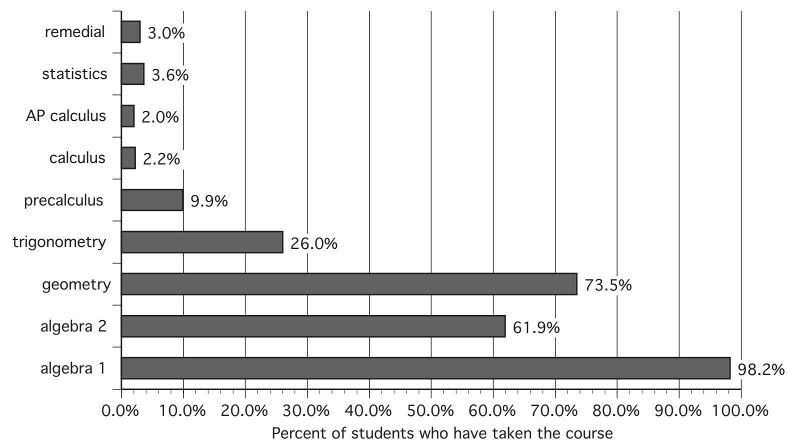


Figure 11a
Comparison of AiS Seniors with National Sample of High School Graduates
by Selected Math Courses Taken

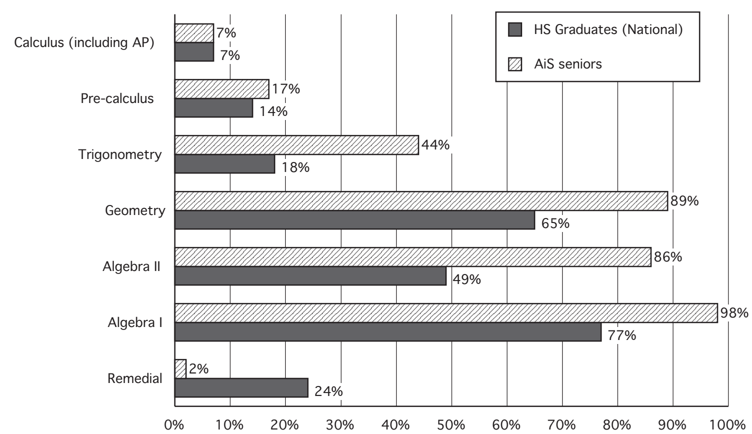


Figure 12
Science Courses Taken by AiS Students
(n=863)

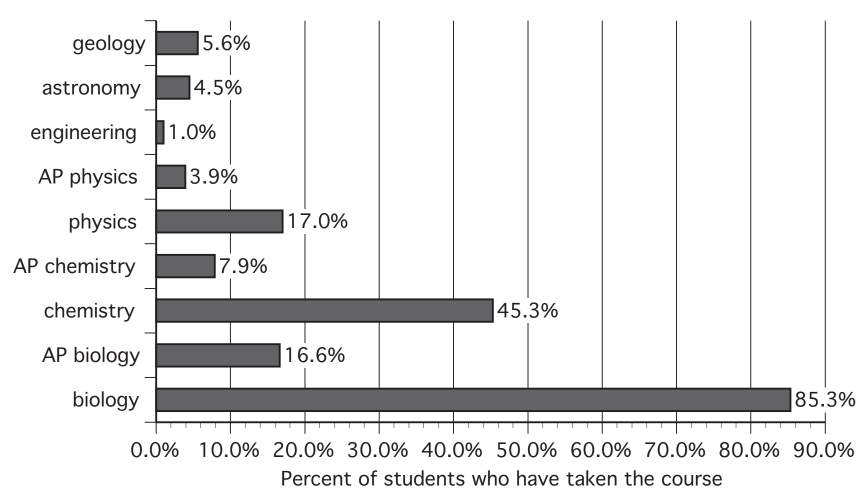


Figure 12a
Comparison of AiS Seniors with National Sample of High School Graduates by Selected Science Courses Taken

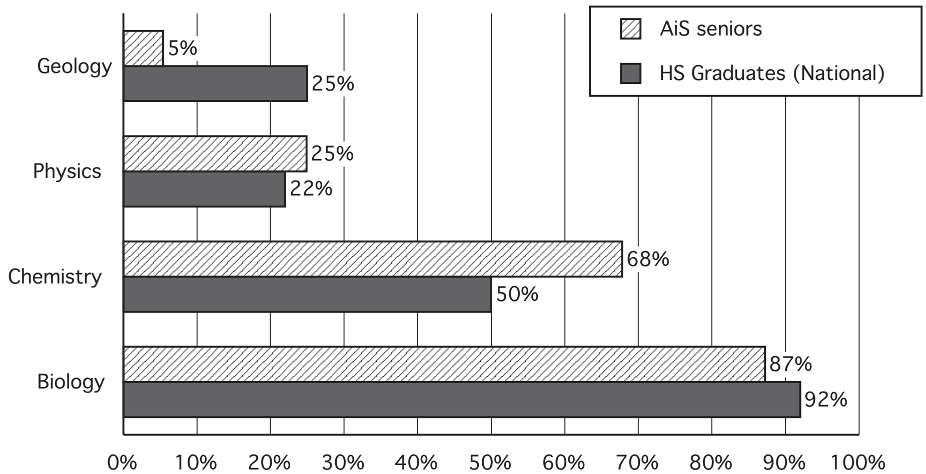


Figure 13
Proportion of AiS Students who have taken Math Courses by Sex

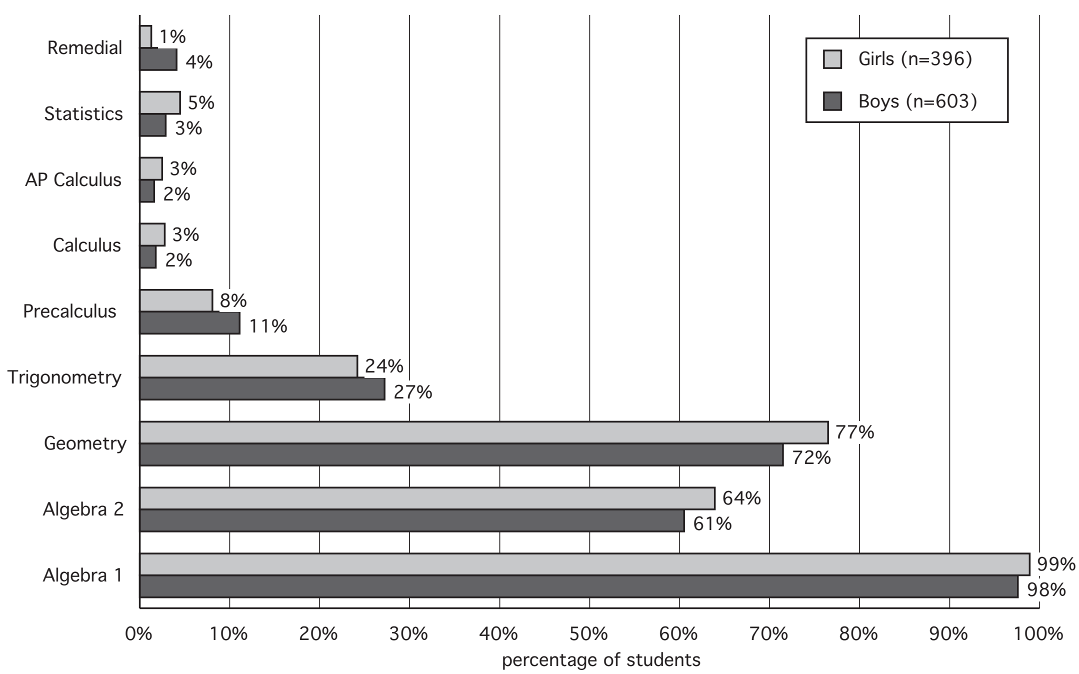


Figure 14
Proportion of AiS Students who have taken Science Courses by Sex

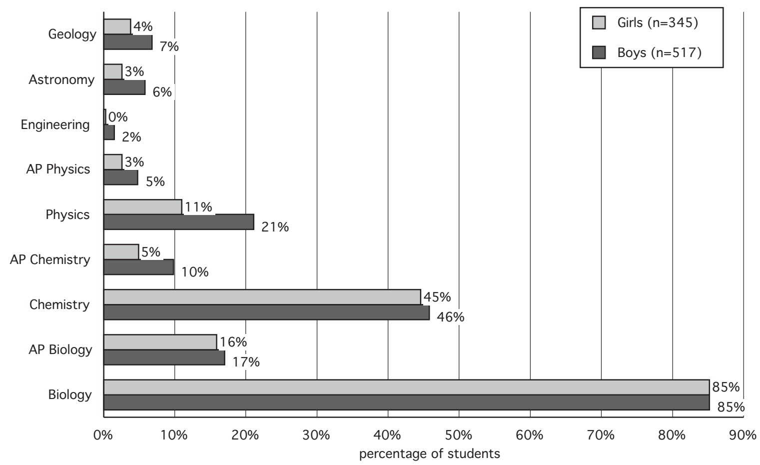


Figure 15
Percentage of AiS Students Who Have Taken Selected Mathematics Classes by State
(n=1000)

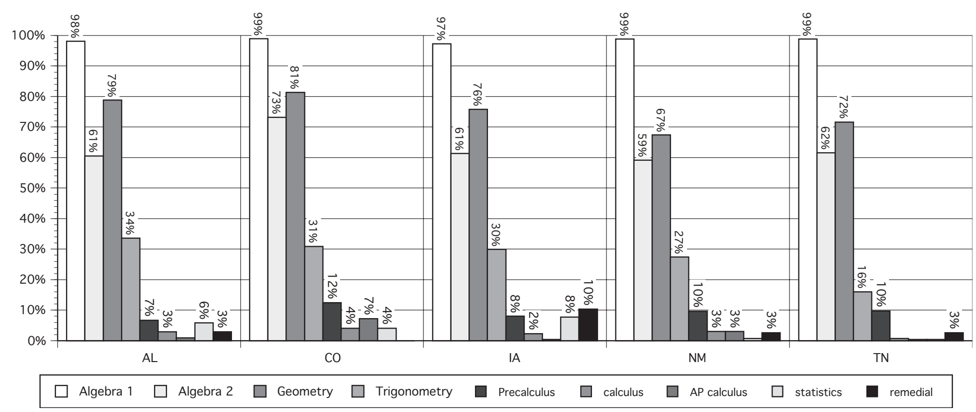
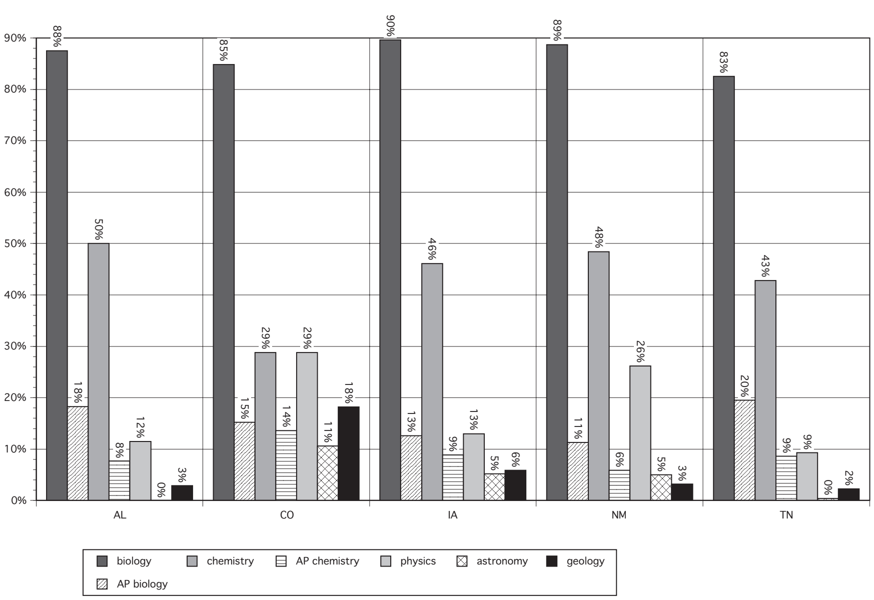


Figure 16
Percentage of AiS Students Who Have Taken Selected Science Courses, by State



were afraid to ask questions in these classes. They were also asked how often they worked in teams in math, science and AiS classes, and how interested they would be in learning more about jobs in science, math, and engineering fields. Attitudes were measured on a four-point scale (0 = never, 3=always). Because of a high level of concurrent validity between survey elements, attitude questions could also be combined to produce an overall measure of students' mean level of enthusiasm about their coursework, as measured at the beginning and end of the year. 678 students completed both the pre- and post-tests and their responses are reported here. This sample includes 263 girls (38.8% of the group) and 415 boys (61.2%).

There was almost no change in students' attitudes toward science classes during the course of the year. The pre-test mean level of enthusiasm about science was 2.32 (out of a possible score of 3), and the post-test mean level was 2.33. Both girls and boys mean scores remained almost constant; boys moved from a mean of 2.35 to a mean of 2.37, and girls moved from a mean of 2.26 to a mean of 2.27.

Students' responses to the individual attitude questions about science also varied minimally between the beginning and end of the school year (see Table 1 for a summary of changes between pre- and post-test means). Students rated themselves as "sometimes" or "always" curious about science (mean post-test score 2.4), and said that they "sometimes" felt confident and "sometimes" felt successful in science classes (mean post-test score 2.03 and 2.10, respectively). The mean score for "like to go to class" was above "sometimes" (mean score 2.21). Students also did not seem hesitant to ask questions, rating themselves "rarely" or "never" afraid to ask questions (mean post-test score 0.89).

Table 1

How often does science make you feel...

	Pre-Test Mean	Post-Test Mean	Change in Score
curious?	2.43	2.40	-0.03
stupid?	1.17	1.20	0.03
confident?	2.03	2.08	0.05
successful?	2.10	2.16	0.06
like you want to go to class?	2.21	2.21	0.00
afraid to ask questions?	0.92	0.89	-0.03

(0= never, 1= rarely, 2= sometimes, 3= always)

Student attitudes about mathematics also remained stable across the school year. The pre-test and post-test mean score on the combined measure of enthusiasm was 2.20 (out of a possible score of three). Girls' scores reflect a slight downward trend, moving from a mean of 2.21 to 2.16, and boys' scores shifted up from a mean of 2.20 to 2.23.

Table 2

How often does math make you feel...

	Pre-Test Mean	Post-Test Mean	Change in Score
curious?	1.92	2.01	0.09
stupid?	1.22	1.31	0.09
confident?	2.07	2.10	0.03
successful?	2.20	2.18	-0.02
like you want to go to class?	2.05	2.02	-0.03
afraid to ask questions?	.90	.82	-0.08

(0= never, 1= rarely, 2= sometimes, 3= always)

There was also minimal change in students' responses to the individual attitude questions about mathematics (see Table 2 for a summary of changes between pre- and post-test means). Students rated themselves as "sometimes" curious about math, and said that they "sometimes" felt confident and "sometimes" felt successful in math classes (mean post-test scores of 2.01, 2.10., and 2.18, respectively). They also reported that they "sometimes" liked to go to math classes (mean post-test score 2.02). The score for feeling stupid was above "rarely" (mean post-test score 1.31). Again, students did not report any hesitation in asking questions, ranking themselves as less than "rarely" afraid to ask questions (post-test mean score 0.82).

Students were only asked attitude questions about AiS at the end of the year. The questions asked were consistent with the questions about science and mathematics classes. Student responses are summarized in Table 3. Students reported "sometimes" or "always" feeling curious in AiS class (mean score 2.43), and "sometimes" feeling successful or confident (mean scores 2.00 and 2.05, respectively). Wanting to go to class was rated highly, between "sometimes" and "always" (mean score 2.40). AiS class made these students feel stupid "rarely" or "sometimes" (mean score 1.42), and rarely made them afraid to ask questions (mean score 0.76).

Table 3

How often does AiS class make you feel...

	Mean Score for AiS	Post-Test Mean for Science	Post-Test Mean for Math
curious?	2.43	2.40	2.01
stupid?	1.42	1.20	1.31
confident?	2.00	2.08	2.10
successful?	2.05	2.16	2.18
like you want to go to class?	2.40	2.21	2.02
afraid to ask questions?	0.76	0.89	.82

(0= never, 1= rarely, 2= sometimes, 3= always)

In the spring administration of the attitude survey students were asked how often they worked in teams in their math, science and AiS classes. Students reported that they "sometimes" or "always" worked in teams in AiS (mean score 2.45), that they "sometimes" worked in teams in science classes (mean score 2.01), and that they "rarely" or "sometimes" worked in teams in math classes (mean score 1.49).

Student interest in the math and science professions was high, and remained almost stable across the school year, dropping very slightly. Student responses to this question were ranked from 1 (definitely not interested) to 4 (very interested). The mean pre-test score was 3.15 (interested), and the mean post-test score was 3.06. Girls' interest in these careers was lower than the boys', and dropped slightly between the pre- and post-test (mean pre-test score 2.91, mean post-test score 2.78; change=0.13). Boys' interest was higher, but also dropped slightly (mean pre-test score 2.20, mean post-test score 3.24).

Discussion

Data indicate that the AiS program is reaching more boys than girls – the sample is 60.8% male and 39.2% female. In comparison to the ethnic makeup of the populations of the states included in this program, the program is succeeding in attracting a significant number of students of color. In three of five participating states, the student population is more than 40% non-white; the Alabama student population has a significant African-American presence (36.6%), and Colorado and New Mexico include large numbers of Hispanic students (39.6% in Colorado and 34.4% in New Mexico). Socio-economically, the program is reaching a wide range of students, distributed relatively evenly across a broad range of backgrounds.

Several indicators in these results suggest that male AiS students have a moderately but consistently higher level of prior access to and experience with technology than female AiS students. Boys are more likely than girls to have computers and modems at home; they are more likely to report familiarity with a range of computer applications; and they are more likely to report knowing various computer programming languages. While some of these data were not collected quantitatively during the 1993-1994 AiS evaluation, qualitative and observational data from that evaluation suggested that students with previous programming experience, who were fluent with the technologies involved in the program, and who had access to technology at home, were better prepared to perform well in AiS than students who did not bring these experiences into the class.

AiS students' math and science backgrounds vary widely. The Algebra I prerequisite for participation in AiS seems to be functioning effectively, as 98.2% of the entire student pool reported having taken the course. Overall, students are bringing more mathematics background to AiS than science background: a majority of students reported that they have taken Algebra II and geometry (61.9% and 73.5%), while biology was the only science course a majority of AiS students reported having taken, and numbers dropped sharply for other science courses (chemistry, the next most common science course, was reported by only 53% of students). The student populations of all five states include some percentage of students who have already taken one or more advanced placement science courses.

Data collected on past course-taking in math and science suggests that AiS students are bringing a substantial amount of mathematics background to their AiS experience, relative to nationwide norms. Nationwide, only 49.2% of high school graduates ever take Algebra II, while 88.5% of seniors in the AiS program have taken it. AiS seniors are also more likely to have taken Algebra I, geometry, trigonometry, and pre-calculus than high school graduates nationwide. AiS students are more typical in their science courses — chemistry is the only science that AiS seniors are more likely to have taken than high school graduates nationwide.

Attitudinal data do not demonstrate any changes in student attitudes toward math or science during their year in AiS. They do, however, show that students bring a relatively high level of interest in mathematics to the course, and slightly less interest in science. Students also exhibit positive attitudes about AiS class, giving it higher ratings than either science or math classes for making them feel curious and making them want to go to class.

Teacher Demographics

Method

Teachers surveys were solicited from 150 teachers currently involved in the AiS program. This report summarizes findings from 109 returned surveys. This total represents 10 teachers from Alabama, 12 from Colorado, 22 from Iowa, 30 from New Mexico and 35 from Tennessee. 41 respondents reported that they were from the 1994-95 cohort, 38 from the 1993-94 cohort, and 27 from the 1992-93 cohort (n=90).

Results

Teacher age, sex and ethnicity. The mean age of AiS teachers is 43.5 years (n=109). This is slightly higher than the national average of 42 (NCES, 1993). Iowa and Alabama teachers are slightly younger than the AiS average, at 41.2 and 41.8 years, respectively, and New Mexico teachers are slightly older, at 45.4 years. Colorado and Tennessee teachers fall close to the group mean, at 43.8 years. Grouping teachers by age ranges, 17% of teachers are between 25 and 34 years old; 33% are between 35 and 44 years old; 43% are between 45 and 54 years old; and 6% are 55 or older. See Figure 17 for a summary.

The AiS teacher population is closely divided between men and women, reporting 53% male and 47% female. This is close to the national ratio for high school (9-12 grade) teachers, who are 48.6% male and 51.4% female. 48% of New Mexico teachers are male, and 50% are female. Alabama and Tennessee have more female than male teachers (Alabama is 40% male/60% female, Tennessee is 46% male/54% female), and Iowa and Colorado have more male than female teachers (Iowa is 68% male and 32% female, Colorado is 67% male and 33% female). See Figure 18 for a summary of these findings.

94% of AiS teachers are Caucasian (n=108). The remaining 6% represents seven teachers, five of whom are African-American. One teacher is Hispanic, and one is Native American. Three of these minority teachers are in New Mexico, three are in Tennessee and one is in Alabama. The national teaching population is 86.8% Caucasian, 8% African-American, and 5.2% other. See Figure 19 for a summary of this information.

Years teaching. Teaching experience ranges widely among AiS teachers, from a low of only one year to a high of 35 years (n=107). Overall their level of teaching experience is slightly above national norms (NCES, 1993). Only 5% have less than three years of teaching experience, compared to 8.1% of high school teachers nationally. 24% have taught for between three and nine years, which is consistent with 23.6% nationally. 36% of AiS teachers have taught for between ten and 20 years, compared to 39.2% of high school teachers nationally; and 35% of AiS teachers have taught for more than 20 years. 29.1% of high school teachers nationally have taught for this long. Tennessee teachers have the most teaching experience: they account for 41% of teachers with more than 20 years experience. See Figures 20 and 21 for a complete report of these results.

Figure 17
Composition of AiS Teachers by Age
(n=109)

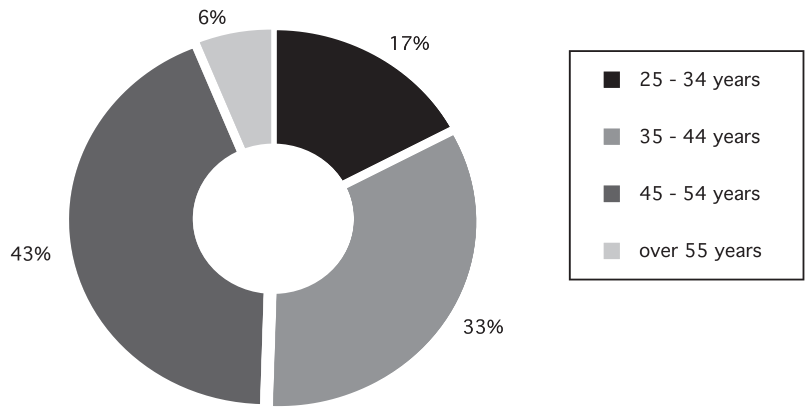


Figure 18
Composition of AiS Teachers by Sex
(n=109)

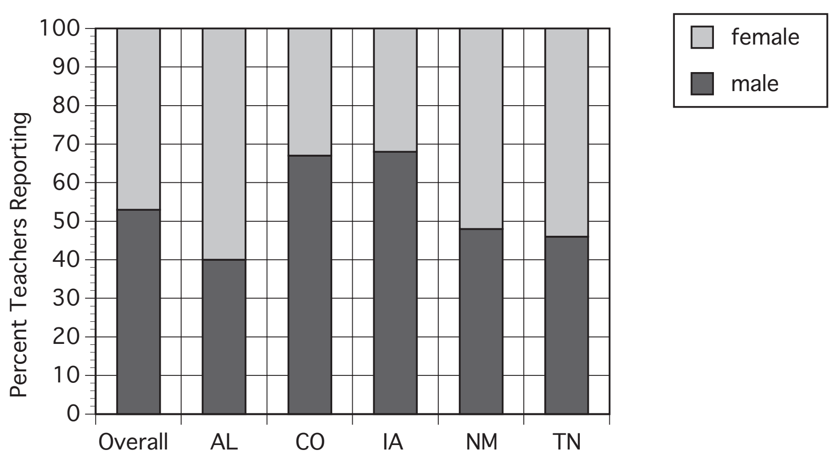


Figure 19
Composition of AiS Teachers by Race
(n=108)

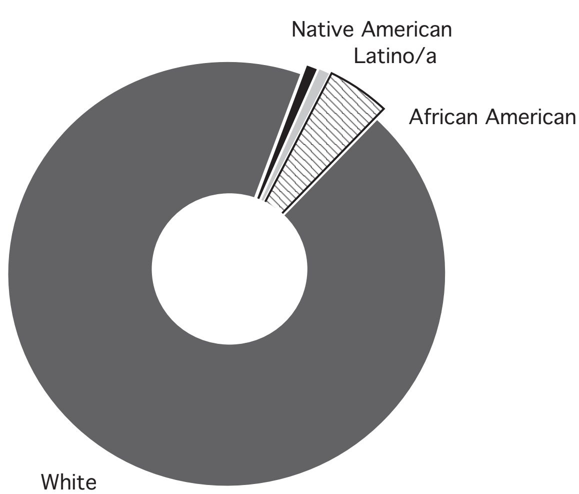


Figure 20
Composition of AiS Teachers by Years of Experience
(n=107)

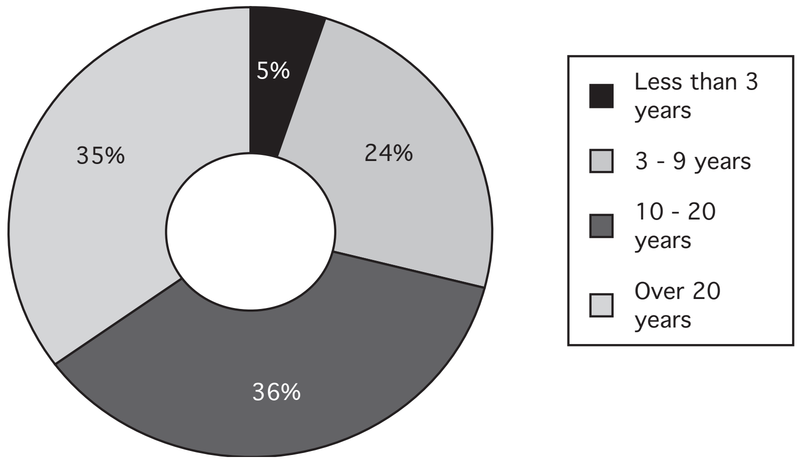
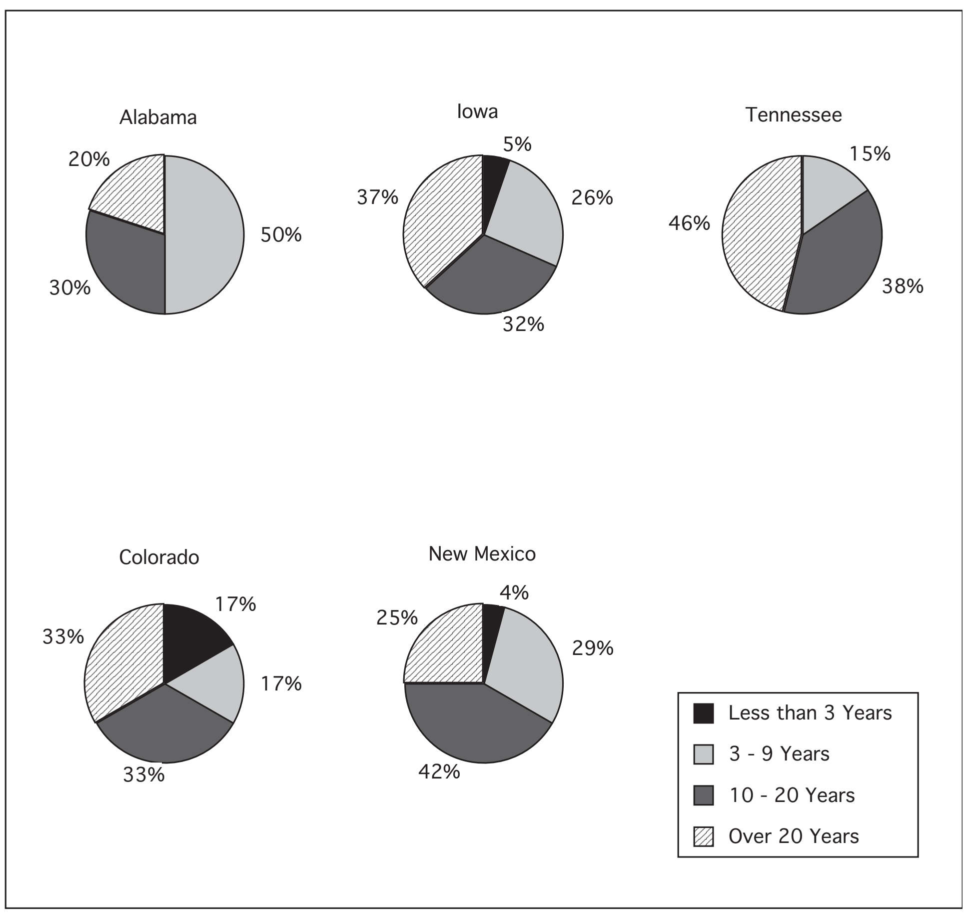


Figure 21
Years of Experience for AiS Teachers by State
(n=107)



Primary teaching assignment and grade levels. 34% of AiS teachers report that mathematics is their primary teaching assignment. 33% report that they are primarily science teachers (biology, chemistry, physics, or general science), and 21% are computer science teachers. One teacher reported that computational science is now her primary teaching area. 10% reported primary teaching responsibilities in other disciplines.

14% of AiS teachers are teaching seventh and eighth graders. A majority of teachers, 68%, teach ninth graders, and 86% teach tenth graders. Almost all AiS teachers reported teaching eleventh graders (94%) or twelfth graders (93%).

Experience with and access to technology. The AiS teachers report a group mean of 5.7 years of experience with using computers in their teaching. 40% reported less than five years experience; 33% reported between 5 and 9 years; 21% reported 10 to 14 years; and 6% reported fifteen or more years. Not surprisingly, these teachers reported significantly less experience with using telecommunications in the classroom. As a group, they report an overall mean of 2.3 years of experience with teaching and telecommunications. 31% reported that they had been using telecommunications as a part of their teaching for one year or less; 28% reported two years of experience, 28% reported three years, and 13% reported four or more years.

Teachers reported slightly more experience (a mean of 2.7 years) with using telecommunications for their own professional development. 25% reported one year or less of experience; 29% reported two years, 25% reported three years, and 21% reported four or more years.

When asked what programming languages they were familiar with, 96% of AiS teachers reported knowing Fortran, and 78% reported knowing BASIC. A smaller number of teachers reported knowing PASCAL (29%), LOGO (21%), or C or C++ (15% for C and C++ combined). 22% reported knowing some other language, such as COBOL. (Multiple responses were possible.)

84% of AiS teachers report that they have a computer at home. At least 75% of teachers in every state have computers at home, and in Colorado all twelve respondents (100%) have them. Of those teachers with computers at home, 76% have modems as well.

Discussion

The AiS teachers are an experienced group, with fewer novice teachers and a greater number of teachers with twenty or more years experience than national averages, and they are slightly over-representative of male and Caucasian populations. More than half of the AiS teachers (60%) have more than five years experience with using technology in their classrooms. This suggests that they may be well prepared to navigate any logistical or technical hurdles to implementing the AiS curriculum, and more importantly, that they are likely to have developed effective practices for making technologies integral to their teaching and their students' learning.

The proportion of AiS teachers with home access to technology is high. In every state, at least three out of four teachers have a computer at home, and three-quarters of those with computers at home also have modems. Home access to these technologies gives teachers a greatly expanded amount of time to spend learning new skills, exploring telecommunications resources, preparing materials, and expanding their knowledge of the computational tools their students are expected to use in their work.

School Demographics

Method

Information on the technology background of the AiS schools and the demographic profiles of their teachers and student populations was collected from the principals of participating AiS schools during November, December, and January of 1994-1995. Data taken from administrator surveys represents 62 high schools and junior high schools in the program.

Results

Size and location of schools. The mean number of students enrolled in AiS schools was 1090, representing a range from a minimum of 82 students, to a maximum of 2,480. Nearly half the schools (49%) were smaller than 1,000 students and another 25% are larger than 1,500. A plurality of AiS schools reported in the administrator surveys were in rural settings: 19 (30.69%) were in rural (but not farming) communities and eight (12.9%) were in farming communities. Seven schools in the program (11.3%) were in small towns of under 20,000 inhabitants, 15 (24.2%) were in small cities, 12 (19.4%) in large cities and one (1.4%) was in a suburb (see Figure 22). This distribution of schools differs from the national distribution, in which 55% of schools are rural, 27% are urban, and 18% are suburban (NCES, 1992).

Student populations. These schools' populations included an average of 38.1% students of color, ranging from less than 1% to 97%. An average of 34% of the student population in AiS schools was living below the poverty line — as indicated by percent of students eligible for subsidized lunches. This number ranged from a low of 3.6% to a high of 99.5% and was slightly higher than the national average (25.9%) of students living below the poverty line. The mean percentage of college-bound students from these schools was 45%, ranging from a low of 20% to a high of 70%.

The demographics by state give a more detailed picture of the characteristics of the schools involved in the AiS program. The following descriptions refer to individual schools or small numbers of schools, to highlight the range of school populations being served in AiS schools. See Figure 23 for an overview of race breakdown of school populations by state.

Alabama. Alabama had nine schools in the program, eight of which completed the survey. The statewide mean percent of students eligible for subsidized lunch eligible was 51.2%; two schools were over 60% each. Four schools were over 70% African American students and two were over 70% white (one of which listed 11% Native American students).

Colorado. Colorado is represented by seven out of the ten schools involved in AiS. The overall mean for subsidized lunch was 34.9%. One school was over 70%. Two reporting school were over 70% Hispanic, four were over 70% white and one was fairly mixed between African American and white students.

Iowa. Fourteen of Iowa's fifteen schools completed this part of the survey. Overall mean for subsidized lunch was 22.2% and no schools were above 40%. One school of the fourteen was under 70% white with 18% African American and 14% Asian or Pacific Islander. Another school has a 25% African American student population and 70% white. The remaining twelve school are at least 80% white.

New Mexico. Eighteen of New Mexico's twenty AiS schools responded. Overall subsidized lunch is at 45% with two school at 100% eligible and another three schools over 70%. Four schools are over 80% Hispanic, another six are between 50 and 80% Hispanic, and two are approximately 40% Native American, and one school is over 70% white and two school are around 40% Native American.

Tennessee. All of Tennessee's fifteen schools completed the survey. The

Figure 22
Composition of AiS Schools by Size/Location of Community
(n=62)

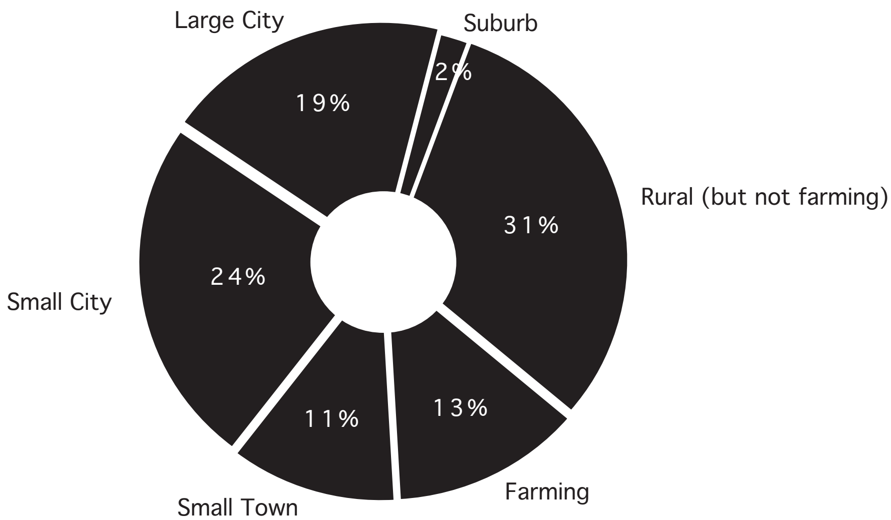
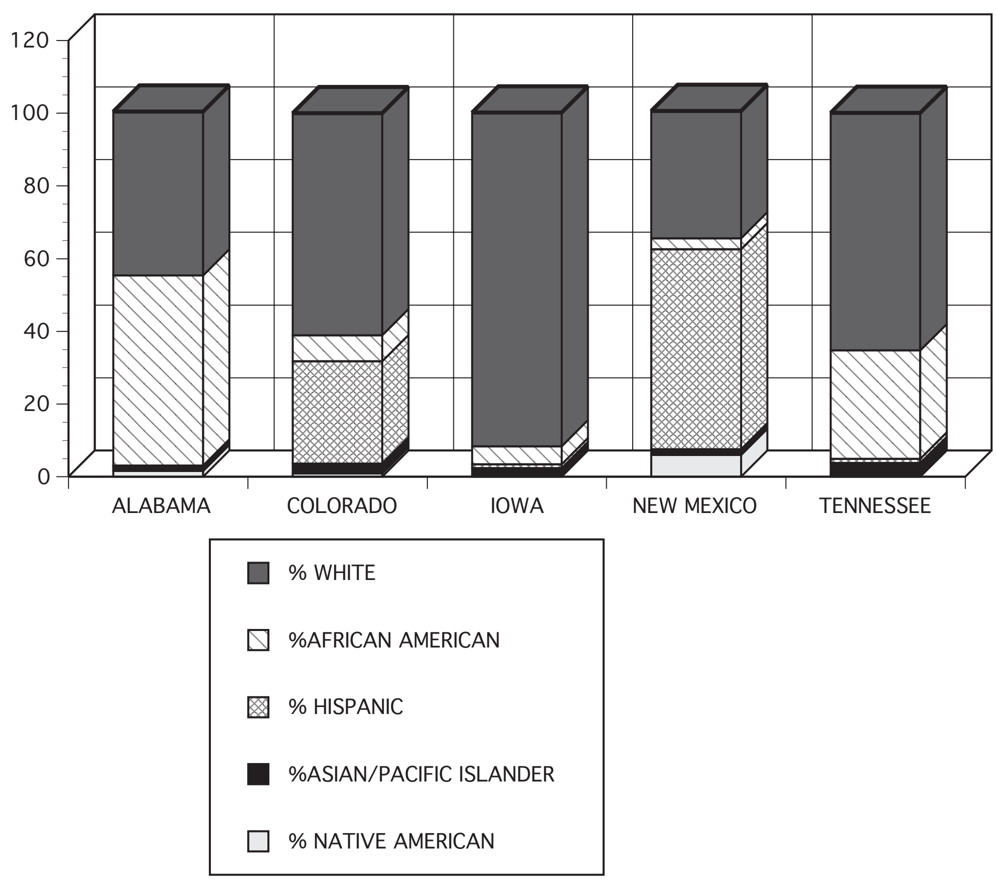


Figure 23
School Populations by Race by State



statewide mean for subsidized lunch is 28%, with one school over 60%. Three schools are over 70% African American, and five schools are over 90% white with one more at 77%.

Technology use in schools. The principals of AiS schools reported an average of 10.9 years of educational technology use in their schools, ranging from a low of one year to a high of 33. Half the schools (n=34) reported that a third or less of their staff used computers in their teaching; another quarter (n=12) estimated from 33 to 50% of their staff was using computers. The final fourth of the schools (n=16) ranged from 60% to a high of 99% of their staff using computers. The percentages of staff using telecommunications in their teaching are lower. Forty schools surveyed (66%) had only 10% or less of their staff using telecommunications. Only five schools reported that more than 30% of their staff used telecommunications in the classroom.

Student/teacher ratios. Student/teacher ratios for high school students in AiS schools ranged from 8/1 to 32/1, with an average of 21/1 (standard deviation 6.1).

Contextual Data: *Teachers' Reports of Program Implementation*

Number and type of AiS programs offered. One section of the teacher survey asked AiS teachers to describe how the AiS curriculum is being implemented in their school. Our interest was in determining how the AiS curriculum is reaching students, by finding out how many schools have been able to establish dedicated AiS courses, and in what other ways the curriculum is being used in schools. For example, in a particular school, there may be a team of teachers co-teaching a for-credit computational science class; but they may also run an after-school, non-credit club, and they may sponsor several students who are receiving credit for AiS projects but are enrolled in courses other than AiS. In this schema, these three implementations of the program count as three different AiS "experiences." Table 4 summarizes the findings. The total n for the table (93) is larger than the number of schools represented (n=62) since many schools offer multiple AiS programs (such as both a for-credit class and an after school club).

Table 4

Types of AiS Programs Offered

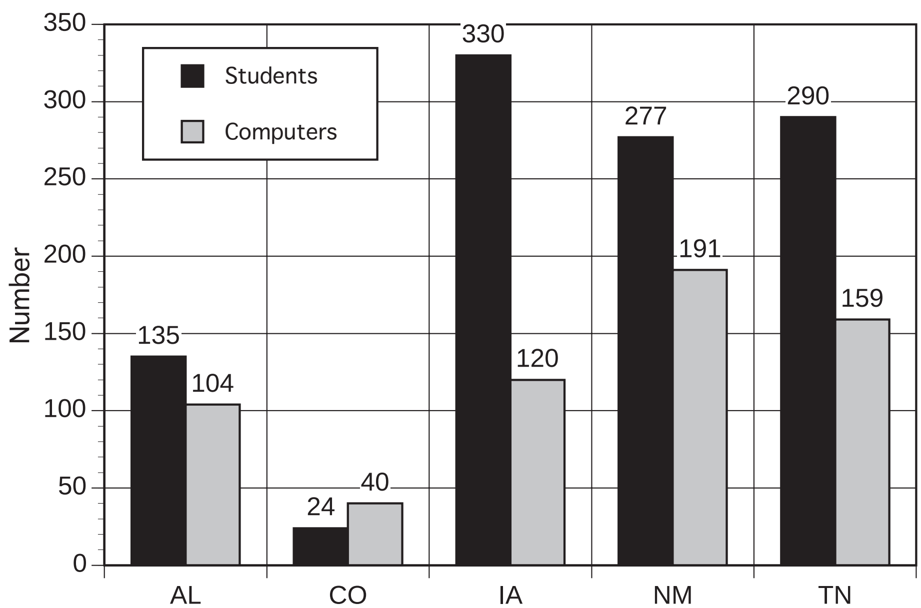
	Dedicated Class	Pull-Out (For Credit)	Integrated into Other Course	After-School (No Credit)
Number Offered	63	4	12	14

(n=93)

Across the 62 schools and 109 AiS teachers represented in the data, there are four distinct ways in which AiS is being implemented, which represent a total of 93 AiS experiences. This includes teachers' reports of dedicated (i.e. stand-alone) courses; allowing students to participate for credit but on a pull-out basis; integrating the AiS curriculum into other courses; and after-school, non-credit programs or clubs. 63 of these experiences are for-credit, dedicated AiS classes. 11 of these dedicated AiS classes last for less than a year (either one semester or one quarter). There are 14 non-credit after-school programs. 12 of AiS experiences being offered in AiS schools are courses that are integrating the AiS curriculum into a pre-existing curriculum, and 4 schools use pull-out programs. All 62 of the schools represented reported some kind of implementation of the AiS curriculum.

Computers available in AiS schools. AiS schools have an average of 11.5 computers available for their AiS students' use (not all of these computers are necessarily connected to the Internet or other wide area networks). This ranges from a low of 9.3 computers in Iowa, to a high of 13.9 in Colorado. Alabama and New Mexico are close to Colorado, with averages of 13.8 and 13.4 computers available per school; Tennessee is closer to Iowa's average with a mean of 10 computers available per school (see Figure 24).

Figure 24
Comparison between the Number of AiS Students and the Number of Computers



Team-teaching in AiS. When asked to describe how the AiS teachers at their school work with each other, the most common response (32.1%, n=106) was that one person acts as a lead teacher, and the other (or others) provide various forms of support (acting as a content specialist, teaching particular units, providing technical support, etc.). 23.6% of teachers reported that they co-teach AiS, and an almost identical number (22.6%) reported that they teach the course independently. 16% reported that they are the only teacher at their school that is active in the AiS program, and 5.7% reported that they had some other arrangement with the other AiS teacher at their school (see Figure 25).

Teaching project-based curricula. AiS teachers reported a range of levels of experience with working with students who are engaged in long term project work. A third of the respondents (n=107) say that they sometimes have students working on projects in other classes that they teach, and a third report that they seldom do this. 19.3% report that they often use project work in other classes, and 11% never have students do project work in other classes (see Figure 26). How often teachers used projects in other classes did not vary with the number of years they had been participating in AiS.

Figure 25
Collaboration among AiS Teachers
(n=106)

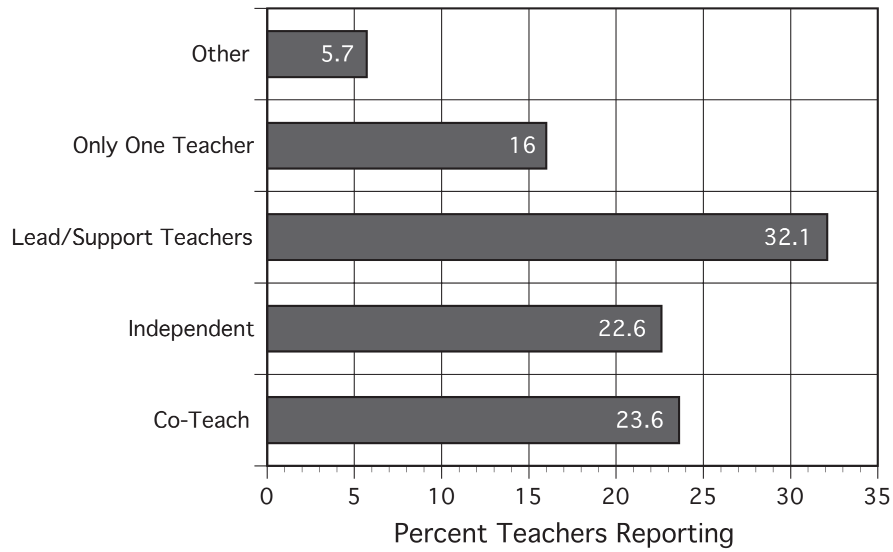
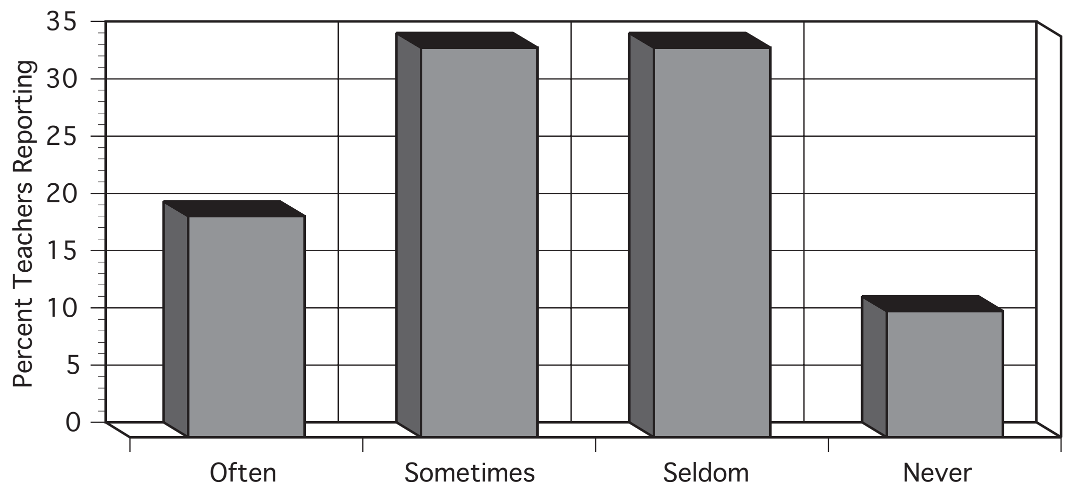


Figure 26
Frequency of Project Use by AiS Teachers
(n=107)



Teaching students working in teams. Many AiS teachers report that they have students work in teams in other classes that they teach. 57% of respondents (n=109) say that they often have their students work in teams in different classes that they teach. Another third report that they sometimes do this, and only 7.3% say that they seldom or never expect students to work in teams in their other classes. Third-year AiS teachers are less likely to report using teamwork in their teaching in other classes: 22% of third-year respondents reported seldom or never using teamwork approaches, compared to 3% of second-year and 0% of first-year AiS teachers.

Teachers' Experiences of the AiS Program

Program objectives. Teachers were asked to rank what they considered to be the most important objectives of the AiS program. Exposing students to interdisciplinary learning, and preparing them for future experiences (college and careers) were ranked most highly by the teachers. Teachers also focused on developing students problem-solving skills, introducing them to computational science, and providing increased exposure to science and technology for women and students of color. The following table summarizes their responses:[8]

Table 5

Ranked Teacher Responses
What do you consider to be the most important objectives of your AiS class?

OBJECTIVE	SCORE
To establish connections between math, science and other disciplines.	67
For students to gain knowledge and/or skills that will be useful in their college experience or future careers.	62
To develop students' problem-solving skills.	55
To introduce students to computational science.	55
To provide increased exposure to science and technology for women and students of color.	53
To give students the experience of completing substantive research projects.	48
To increase students' technical competence.	25
To increase self-esteem and/or confidence.	16
For students to gain experience working in teams.	15
To help students overcome their fear of technology.	6

Mentor's role. Teachers were also asked to rank the roles that they most wanted mentors to play in their students' project work. Teachers strongly indicated that helping students to define their project topics is the most important role that mentors can play. All five of the most commonly chosen responses dealt with this issue: teachers focused on expecting mentors to focus or simplify project ideas; to develop or enhance project ideas; to identify the computational possibilities of a potential project topic; to translate technical material that would support project work; or to provide content-relevant material to support project work.

Table 6

Ranked Teacher Responses
Which three of the following do you consider to be the most important roles for a mentor to play?

ROLE	SCORE
To focus or simplify student project ideas.	114
To help students develop or enhance project ideas.	95
To help students identify the computational possibilities of their project topic.	75
To translate technical material or ideas for students.	48
To provide content-relevant information.	42
To help students with programming	27
To supply algorithms/programs for student projects.	27
To make facilities/resources available to students.	24
To review completed student projects.	6

Most exciting aspects of the program. We asked teachers what they found most exciting about the AiS program, both for themselves professionally and for their students. Responses are summarized in Tables 7 and 8. Teachers responses about their professional interests focused on the access to new technologies that the program provides, choosing "acquiring new technology-related skills" and "access to the Internet" and "using up-to-date resources and teaching methods in my classroom" as the most exciting aspects of the program. For their students, teachers reported that access to the Internet was most exciting, followed by access to computers and computational science tools. Increased motivation about learning was ranked as the third most exciting aspect of the program for their students.

Table 7

Ranked Tacher Rsponses
For you professionally, which three of the following do you consider to be the most exciting aspects of the AiS program?

ASPECTS	SCORE
Acquiring new technology-related skills.	120
Access to the Internet.	115
Using up-to-date resources and teaching methods in my classroom.	115
Access to computers and computational science tools.	92
The opportunity to work with other related teachers and with outside experts.	57
My increased competency as a teacher.	37
Other.	3

Table 8

Ranked Teacher Responses
For your students, which three of the following do you consider to be the most exciting aspects of the AiS program?"

ASPECTS	SCORE
Access to the Internet.	163
Access to computers and computational science tools.	139
Becoming more motivated about learning.	80
Having the opportunity to carry out their own original research.	55
Improving their analytical skills.	44
Having the opportunity to work with mentors.	25

Obstacles. AiS teachers reported that inadequate time for class preparation and planning is their biggest obstacle to successful implementation of the AiS program. Not having enough computers for the number of students involved was also ranked highly, as was the limited amount of class time available, and the difficulty of finding mentors. Responses to this question are summarized in Table 9.

Table 9

Ranked Teacher Responses
What are the biggest obstacles to successful implementation of the AiS program in your school?

OBSTACLES	SCORE
Not enough time for prep work and planning.	137
Hardware limitations (not enough computers).	90
Insufficient in-class time for student work.	71
The difficulties of finding mentors.	67
My own experience with technologies.	36
Inadequate network access (not enough accounts or networked computers, or unreliable network connections).	36
Lack of support from school administrators.	17

Amount of time required to teach AiS. Teachers reported that AiS does take more time to prepare for and to teach than other courses. Only 4% of respondents (four teachers) reported that AiS did *not* take any more time to prepare for than other classes. 28% said it takes a little more time, 40% reported that it takes significantly more time, and 28% reported that it takes far more time than any other class they have taught. With 68% of respondents describing the course as significantly more time-consuming or far more time-consuming than any other, it is not surprising that inadequate prep time remains a major obstacle to teachers' fully realizing their goals for AiS in their schools.

Level of comfort with diverse project content. AiS teachers reported a high degree of comfort with the diversity of project work AiS students engage in. 59% of respondents reported that they actually prefer having students work in a range of content areas, and another 24% said they were comfortable with that situation when it is necessary. Only 17% reported that they were uncomfortable with such a situation, or that they found it difficult to manage.

Discussion

The AiS curriculum is reaching students through dedicated AiS classes, classes that integrate AiS with other curricula, after-school clubs, and a variety of special arrangements that teachers have made to allow students to participate. Teachers' willingness to adapt the curriculum and their schedules in so many ways suggests that both students and teachers are committed to finding the time to pursue AiS projects, even though, as teachers indicate, there is rarely enough time in the school day to accommodate the prep work necessary for the course or for students to complete their own work.

In order to maximize the amount of time available to students to develop their project work, it will be helpful to continue to emphasize to administrators the importance of sustaining full-year, dedicated courses, and developing them in all schools that do not yet have them. Closely related to this issue is the desirability of team-teaching this course. Only a third of the AiS teachers report that they fully team-teach their courses, and almost 40% report that they teach the course alone. Team-teaching will support both teachers and students in the complex task of developing and creating year-long projects. In most schools, however, this is a difficult situation to create, as evidenced by the number of teachers who now teach the course alone or with only the partial support of another teacher. Administrators need to continue to be reminded of the importance of increased time and flexibility for teachers engaged in this program.

Teachers' interpretations of the goals of AiS are focused on the metacognitive skills that are emphasized in the kind of inquiry central to the program. They view the program as multidisciplinary, and want students to gain both skills and intellectual capacities that will be useful to them in the future. What teachers find exciting about the course, however, for themselves and for the students, is the technological components of the program. Access to the Internet was rated the most exciting component of the course for students, and the second most exciting for teachers, after acquiring new technology-related skills. For their own development, teachers are focused on gaining new skills and access to new technologies. Pedagogical changes ("working with other teachers and outside experts," "increasing my competency as a teacher") were not ranked as highly. For students, teachers strongly indicated that the technology was the exciting part of the program, ranking "access to the Internet" and "access to computer and computational science tools" well above other options.

Teachers looks to mentors to provide much of the pedagogical and content-knowledge support that is necessary to put these technologies to work in the service of student learning. Teachers reported a strong expectation that mentors should be able to help define student project topics, to enhance or refine them, or to identify the computational possibilities of potential topics. They also rely on mentors to translate technical material, and to provide content-relevant information. This emphasis on the mentors' role in conceptual project development, may be related to the finding that only a third of the AiS teachers report that they use projects regularly in their other classes. This figure does not increase for the more experienced AiS cohort. These findings suggest that AiS teachers are still struggling with the pedagogical and logistical challenges of supporting project work, and are in large part looking to mentors to help them bridge that aspect of the curriculum.

Time continues to be the obstacle AiS teachers report as most prominent. The lack of time for planning and research may be related to the emphasis teachers are putting on asking mentors to guide the process of project development for their students. As teachers continue to gain fluency with the technical skills necessary to the program, and with the intellectual habits of computational science, they will need to continue to experiment with new ways to recruit and work with mentors, to develop a role for them that both uses their strengths in content areas, but that complements their own role as the central guide and coach in student project work.

School Site Visits

Site visits were made to second year AiS schools in Alabama and Colorado in fall 1994 and spring 1995. Five schools were visited in the fall; eight schools in the spring. Additionally, a subset of third year schools (n=7) in Iowa, New Mexico, and Tennessee were visited in spring 1995. The purpose of these site visits was to examine the ways in which the AiS curriculum was being implemented across regional, school, and classroom contexts, to discern programmatic issues that were of particular concern to teachers, and to observe students' project work.

Method

A team of two researchers visited each site. They shared a checklist of important topics to investigate during the course of the visits and recorded extensive field notes. These notes were shared with all research team members following the visits. Fall visits to AiS classrooms occurred mid-way during the first semester. Spring visits took place 3-4 weeks prior to state Expos in which students were to present their project work.

Findings

Across states and classroom contexts, the topic that emerged most consistently in conversations with both teachers and students was project development. Students and their teachers commented upon similar themes within this topic — revealing multiple facets of this complex endeavor. Most prevalent among the themes they identified were: (1) selecting and framing computational projects; (2) researching and integrating informational resources; (3) using computational strategies/programming to support inquiry; (4) managing time/structuring classroom time; (5) and using mentors effectively.

Selecting and framing computational projects. Tapping away at the keyboard all the while, this third year AiS student contemplated aloud how to determine planetary orbits without using equations. His group's mentor had suggested such a "shortcut" technique because the team had been unable to understand the complex math behind actual astronomical formulas. The group was attempting to simulate planetary motion in order to determine if an exploding asteroid planet could have created the current configuration of heavenly bodies in our solar system.

Diverging for a moment from his explanation, the student suggested that the purpose of projects in "Supercomputing" was to investigate numbers. He described his own project and program as a "number cruncher — [something that] spits out numbers that are not useful to most people." He contrasted it with other programs he had written, particularly those that had been entered in a regional competition. These programs, he said, were "useful to the public." As examples, he mentioned a home improvement calculator and software to help farmers determine crop rotation schedules.

Across the country, four young women clustered around a computer: They, too, were debugging FORTRAN code. Three of the girls were first year AiS students; the fourth was their student mentor, who had been in the program previously. The students enthusiastically described how they had originally planned to study growth hormone, because two of the team's members were very short. Unable to locate substantial information on this topic and uncertain as to how they would turn the topic into a computer program, the students changed their project to cancer. At the time of our conversation, they were attempting to predict how many people would die from breast, lung, and pancreatic cancer in the year 2000.

The students recounted their visit to the regional office of the American Cancer Society and pointed to piles of paper they had collected on the number of deaths per year attributed to these three types of cancers. One member of the group explained how they were using this information to derive their formula. She suggested that they had considered using a logarithmic function but everyone would have died too soon; they decided instead to use a geometric function. The girls admitted that though this project was not as compelling as studying about growth hormone and genetic aberrations, it did lend itself to writing a computer program.

Though their concerns and conclusions about project topics were quite different, both of these student groups (as well as many other students) expressed confusion about what sorts of problems were suitable for computational projects. Students' lack of clarity on this issue was mirrored by their teachers. One teacher, for example, noted that he found it very hard to support computational biology projects. Although reference materials were available, he found that his students had difficulty in applying computational strategies and programming concepts to these topics. Recalling a project on Huntington's Disease from the previous year, he described how students "reverse engineered" this project; they attempted to work backwards from charts and graphs to data. They, then, played with this data to generate new charts, graphs, and conclusions. The teacher was concerned that these methods were "not scientifically correct." Real scientists don't do things this way, he lamented.

Another teacher commented that he would like to have a book describing 100 *good* supercomputing projects. He noted with exasperation that a handful of students had dropped the class because they couldn't focus their topics on something clearly computational. Another teacher also indicated that he had toyed with the idea of developing ten full blown projects himself (projects complete with mathematical models) from which students could choose. He was concerned, though, that students would not be as interested in topics that were pre-selected for them.

Both teachers and students appeared to understand that AiS projects require the use of certain types of computational resources and techniques (programming, visualization). Selecting and framing problems in ways that lend themselves to computational analysis, however, continue to be challenging.

Researching and integrating informational resources. Throughout site visits, AiS students reported and were observed using the Internet (particularly the WWW) extensively. Students' skill at finding and integrating informational resources varied widely within the program. Many students indicated that they had difficulty locating relevant resources, and they suggested that the data they did collect served merely as "background information" — it did not really tie into their programs.

For example, one group of students initiated three different project topics before settling on one which required minimal content research. Originally, the team had planned to study tornadoes and to create a program that would predict the frequency and location of twister occurrences in their state. Unable to locate the precise statistical information that they needed, they instead began to investigate global meteorological events and became particularly interested in the effects of West African wind fluctuations on weather patterns in the Eastern United States. With only one journal article informing this new topic, however, they lacked fuel to move forward and changed topics once again. The group's third and final project topic was to write a program that determined the molecular weights of various amino acids.

Another group of students modeling the dispersion of chemicals across a hypothetical body of water explained that they were planning to write their FORTRAN program first and *then* do research. Content information would be useful mostly in its capacity to beef up their project, they noted.

More common were cases in which students collected generalized information on their topics and then applied it nonsystematically or not at all in their computational maneuvers. For instance, one student described her research on Aurora Borealis in great detail. The 11th grader had become interested in this subject after a professor from Auburn University had visited her physics class and given a slide presentation on the topic. She excitedly explained that electrons and protons from solar winds sometimes got trapped within the earth's magnetic field to create the colorful phenomenon of the aurora. When asked how she would use this information in her project, the student indicated that it was mostly "background information" to help her understand what was happening. She did not know if or how it would inform the event simulation that she hoped to create.

In contrast to these examples, however, there *were* students who finely cobbled their informational resources into mathematical models and computer programs. For instance, in contemplating the fate of the world's manatee population, one student group collected information from the Internet, magazine articles, and an organization called "Save the Manatees." They explained that this research helped them formulate a model to predict the world's population of manatees in twenty years. They noted, for instance, that since scientists do not know the lifespan of the manatee (because they generally base such estimations on dental evidence and manatees lose their teeth regularly), they would have to construct an algorithm that sidestepped this variable. The students did learn that most manatee casualties were the result of human factors such as collisions with boats or entrapment in floodgates and canal locks, and they planned to use statistics on these occurrences in creating their mathematical model. With guidance from their mentor, the team hoped to use this information to specify variable interactions that would help them predict manatee populations at different points in time.

For the most part, we did not observe teachers structuring or guiding their students' Internet investigations or research endeavors. During our visits, their concerns about effective integration of content information were more generally expressed in terms of the flip-side of this issue — integrating computational strategies more holistically into project work.

Using computational strategies/programming to support inquiry. During site visit conversations, teachers never failed to raise the issue of programming and how it could be fit more meaningfully into their students' project work. Most teachers expressed concern about being behind schedule — indicating that they felt it was nearly impossible to cover all the FORTRAN coding in one semester. Teachers' fears of falling behind were often exacerbated by concerns about their own programming skills.

As a result, it was often difficult for teachers to blend project work and programming instruction. AiS teachers employed a variety of strategies to deal with their difficulties. For example, one teacher simply bypassed the programming. Instead, she encouraged her students to gain a numerical "feel" for their project content by guiding them through statistical manipulations on spreadsheets.

Another teacher stressed that learning to write programs was appropriate for only about half of his students; the other half, he remarked, could benefit more from just using and understanding "canned" programs. This teacher noted that if he had his preferences, he would continue to teach programming, but to a lesser extent.

This sentiment was expressed by other AiS teachers as well. One veteran educator noted that last year her students all attempted to write original programs and were disappointed when they could not get the computer to do what they wanted. To remedy the situation this year, she encouraged her class to build on basic programs which they could find in textbooks or reference materials. This year, she also streamlined her programming instruction and tried to organize programming concepts as an English teacher would organize a lesson on composition. Her students were encouraged to think about their programs as essays with an opening statement, variables and formulas to support this statement, and output to inform the essay's conclusion.

Demonstrating a similar spirit of innovation, another AiS teacher tried to teach specific programming concepts (e.g. if-then statements, datatyping, arrays, double arrays, and loops) by engaging students in real world processes that mimicked the concept. For instance, to teach his students the concept of if-then statements, he asked them to write a program simulating the RNA transcription process. In this process, a triplet of RNA bases (e.g. A, C, T, G) is coupled with its corresponding amino acid. So, for instance, an ACT might match up with lysine, whereas AGT might be tryptophan. The whole process can be reduced to a large set of if-then statements. This teacher, an applied mathematician, also required his students to write FORTRAN programs in conjunction with their physics experiments. An example of one such program was code that determined the value of equation variables such as the spring constant (k) in experiments about Hooke's Law.

AiS students also struggled with the task of using computational techniques to *extend their inquiry* in substantive ways. Like their teachers, these students employed a range strategies to deal with the challenge. For some, programming became the focus of project work. Such students often shifted from complex, imprecisely articulated questions to simple programming problems. For example, one group's project consisted of calculating the probability that two people in the same room would have the same birth date.

Other groups managed to incorporate numerical manipulations but in ways slightly tangential to their native project questions. One team of second year students, for instance, became completely captivated with the problem of overweight vehicles and how they affected the lifespan of state highways. The students met with officers from the state Department of Transportation and visited a weighing station; they spoke excitedly about how overweight trucks siphoned off public monies by destroying roads. Rather than pursuing this issue with a computational model, however, the students generated a FORTRAN program which calculated the fine that would be levied against an overweight vehicle based upon the degree to which it violated state weight restrictions.

Still other groups were able to go as far as representing certain phenomena with computational models. They stopped their inquiry, however, just before deriving insight from the models they created. For example, one pair of students sought to simulate electrophoresis — a procedure by which individual DNA and protein molecules are separated and identified. The students researched the extensive biomedical uses of this technique and acquired a simplified algorithm describing how it worked. Using this information, they wrote a FORTRAN program and generated a number of graphs. When questioned about their visuals and algorithm, though, the students expressed considerable confusion. It became clear that the crucial variable of time was not represented in their simulation, and without it, the comparisons they made were somewhat meaningless. Though their program worked, the students were not able to reflect upon its accuracy or meaning.

Some AiS students were able to integrate computational methods of solution into their project work quite successfully. For instance, one AiS student (part of a team investigating evolving artificial intelligence) described his curiosity about how cellular automata would evolve given a specific set of inherited preferences — a “genetic code.” Excitedly, he explained that once the team had gotten its program to run, the automata (dubbed “ants”) began to exploit the reproduction algorithm he had established for them. “They were out of control,” he exclaimed. To solve this problem, the student had to revisit not only his program code but also the theory behind his genetic code. After much work and with great satisfaction, the team discovered an error in its conceptual model of inherited preferences.

Another group of students that effectively integrated computational strategies into their project inquiry studied the archaeopteryx — a winged dinosaur. These students wanted to find out if the archaeopteryx could fly, and if not, how it got around using its wings. With the help of a mentor (a graduate student in paleontology), the group investigated the bone structure of the archaeopteryx and studied the physics of flight. Based on their research, the team of first year AiS students determined that this creature could not fly on its own because it lacked a sternum, the bone strong enough to support muscles necessary for flight. To determine how it did move, they created a physical model of the “bird” and tested it in a wind tunnel. From this data, they concluded that the archaeopteryx was a climber and a glider and that the angle and height from which it descended determined how far and fast it could move.

Such snapshots exemplify how AiS teachers and students attempted to use computational techniques to support project-based inquiry. Developing computer programs that actually extended student’s understanding and knowledge of the phenomena they were studying, rather than simply computing already known results, continued to be challenging. However,as evidenced in site visit observations, students and teachers approach this challenge with a range of strategies and great ingenuity.

Managing time/structuring classroom time. In reference to programming issues and when discussing how their teaching practices had changed in the last year, teachers overwhelmingly indicated that their teaching had become much more organized. To structure their classes, teachers had begun using more concrete lessons and implementing stricter deadlines. Deadlines, in particular, figured prominently in teachers’ descriptions of organizational improvements they had made to their AiS classes.

Even with these adaptations, however, teachers continued to view time management as an enormous challenge. One teacher, clearly frustrated with the issue, suggested that next year he would have students write “hard line code” until three weeks before the Expo deadline at which point they could begin their project work. He felt that long-term projects encouraged students to waste time and just surf the Net. For this reason, he felt he had to be constantly on top of what the kids were doing,and this was not his preferred style of teaching.

AiS students also alluded to difficulties they experienced in pacing their project work. During spring site visits only weeks before their state Expos, some student groups indicated that they had only begun seriously working on their projects in the week prior to our visit. Other groups reported that their programming and research had been completed for some time and that they only needed to refine their project displays. The latter of these students were often engaged in closed-ended endeavors such as generating fractal landscapes or computing the wave characteristics of middle-C.

Situations such as these, among both teachers and students in the AiS program, demonstrate the continued need for support in pacing project development as well in selecting and developing computational projects that are rich enough in content to sustain long-term investigation yet focused enough to facilitate meaningful inquiry.

Using mentors effectively. In maneuvering through these complex processes, AiS teachers and students often looked to external mentors for assistance in narrowing down project topics, locating content information, providing hands-on experiences, and employing computational strategies (formulas, program structure). Teachers repeatedly expressed their conviction that mentors were an essential part of the AiS program. One teacher reported that mentors were absolutely necessary because they could provide direction and keep students from wasting time and energy. Students communicated similar sentiments, and they pursued the mentor experience with great determination and ingenuity.

Teachers, family friends, and relatives continued to supply most mentor contacts. On its own (in the absence of more personal contacts), the Internet proved to be of questionable merit in locating mentors. More often than not, teachers and students suggested they had been disappointed by Net responses to their public postings for assistance. For instance, when one project group, studying bridge construction, posted a request for mentors on a popular civil engineering listserve, they received no replies. Suspecting that their query was too general, the students posted again — this time asking very specific questions about materials. They received only one reply suggesting that their project was too difficult and they should give it up. Similarly, when two students posted questions on a hydrology BBS, they received numerous flames. The students noted that they were hurt by this harsh response. Commenting on the “put downs” that his students had received on Internet newsgroups, one teacher said he thought the Internet was becoming clogged with requests from needy high school students. Students who used telecommunications technology to communicate with mentors, but not necessary to locate them, tended to have far better experiences.

This year, there were also several “in-house” human resources available for AiS students. Teachers in two states hosted student teachers. In one case, the teachers-in-training became project mentors — helping students fill in knowledge gaps. In another case, students indicated that the teacher-in-training spent most of his time perusing the Internet but occasionally directed them to useful resources. A few AiS classes also had the opportunity to work with scientists and engineers who visited their classes regularly as part of industrial (e.g. NASA) mentoring initiatives.

Mentors appeared to have been a mixed blessing in the AiS experience. Occasionally, mentors suggested that student-initiated topics were unreasonable or they pushed students toward topics that were not innately compelling. This generally resulted in a decrease of student interest and motivation. For instance, one pair of students with a common interest in music and particularly percussion had hoped to develop a project on drums and sound waves. Their mentor, however, did not have expertise in this area and directed them instead towards the topic of kinetic energy with which he was more comfortable.

In the best of situations, mentors supplied real-world contexts for student explorations. They enabled students to gain first-hand insight on the problems they had selected to study. They helped students reason through the murky processes of mathematical modeling, and they provided consistent feedback on student work — encouraging them think critically about their problem statements, methods of solutions, and conclusions. Students working on the archaeopteryx project, for instance, spoke in glowing terms about their mentor. They said that he did not just answer their questions. Instead, he asked *them* questions and he would not respond until they had at least speculated on solutions. Similarly, students in New Mexico who were interested in issues of water conservation worked closely with a district conservation representative. Benefiting from field visits and frequent mentor communication, the students were able to create a program to determine the most efficient and economical method of irrigation given the specific crop, acreage, water depth, and well output. The students' mentor plans to use their program in his work.

Student-mentor interactions assumed a variety of forms. However, those relationships that were most successful generally involved mentors who understood that their role was one of guidance. These mentors did not direct or conduct student inquiries; they merely commented on and helped to shape students' own intrinsic interests and questions.

Learning Process Data

AiS students spend a substantial portion of the school year developing and revising complex research questions. To chronicle their experience during the year and to observe the development of their thinking over time, we designed a series of *journal question*s that were administered to AiS students on a regular basis (monthly for those students enrolled in full year programs).

Journal questions were intended to collect specific pieces of information, such as project topic, program logic (input, output, operations), and relationships with mentors, as well as to probe student understanding of the content areas involved in their projects and the research processes in which they were engaged. The original journal questions were developed in collaboration with AiS state coordinators in 1993. In order to insure that journal data would be comparable over the duration of the program evaluation, these questions were kept fairly consistent for 1994-95. However, based on last year's student responses and when appropriate, some questions were made closed-ended. Additional questions were also developed to probe student-mentor relationships and to obtain a clearer sense of how students developed their computer programs.

Method

Journal questions were distributed via e-mail at the beginning of every month[9] to AiS teachers and students. Students were instructed to send their responses to the researchers by the end of the month; they were also encouraged to send copies of their responses to their teachers. Consistent with protocols from last year, journal codes were developed based upon themes that emerged in student responses. In most cases, this year's codes were identical to those from last year. However, in some instances, students commented on new issues (for example, several AiS students specifically mentioned that they expected to work in teams); such items were reflected in this year's coding.

The journal data presented here document how high school students in the AiS program develop and describe their projects. Students participating in this portion of the evaluation represent fourteen classes[10] across five states. Their answers to monthly journal questions provide insight about several aspects of the program (see Table 10).

Table 10

Aspect of AiS Program	Sample Journal Questions	Month
Motivations for enrolling in AiS and expectations of the course	• Why did you decide to take this class? • What did you expect this class to be about?	September
Selection and characterization of preliminary project topics	• Tell us about your project topic.	October
Early use of classroom computer resources	• Tell us how your project or the way you worked on your project would change if you did not have access to a computer.	November
Selection and characterization of initial project groups	• Are you working alone or in a group? • If you are working in a group, did you: __ Select your own group __ Get assigned to a group by your teacher __ Other (please specify)	November
Selection and characterization of initial project mentors.	• Do you have a mentor for your project? • How often do you communicate with your mentor? • What kind of help do you think would be most valuable to receive from a mentor?	December
Integration of programming into project work	• Are you writing a computer (FORTRAN, C...) program for your project? •What do you expect your computer program will do for your project when it is completed?	January
Integration of visualization techniques into project work	• Are you using visualization tools in your project? • What do you think your visualization will communicate about your data?	January
Project questions and use of computing to answer them	• When you think about your project, what questions are you most curious to find the answers to? • How do you think computing will help you find the answers to these questions?	February
Project difficulties	• What is most difficult about your project?	March
Late-year mentor interactions	• Do you have a mentor for your project yet? • How did you find your mentor? • How does your mentor help you with your project?	March
Project changes and their causes	• What about your project has changed since the beginning of the semester? (check all that apply) [list included] • What caused you to the make the changes you did?	April
Self assessment	•If you could go back and do your project again, what would you do differently?	May

Comparisons of journal responses across year (1994-95 vs. 1993-94) and select demographic variables (student sex, grade, and previous AiS experience) were also made. They are reported here when appropriate.

Results: First Semester

Student motivations and expectations. Soonafter they began the school year, students were queried about why they enrolled in AiS and what they expected the course to be about. 70.8% (n=182) of the students who were queried responded, and journal codes were developed based on the themes that emerged.

Motivations. Student motivation was coded as taking the form of: personal enrichment; social; enjoyment; future orientation; encouragement by a teacher; encouragement by a friend or relative; and other. Motivations coded as *social* included connective (desire to meet people and make friends) as well as altruistic intentions, motivations coded as *future-oriented* generally referenced college or career plans, and *other* motivations included items such as testing out of other classes offered during the specified period or hoping to win scholarships from supercomputing competitions.

Figure 27
Student Motivations for Enrolling in AiS
n=182
(multiple responses possible)

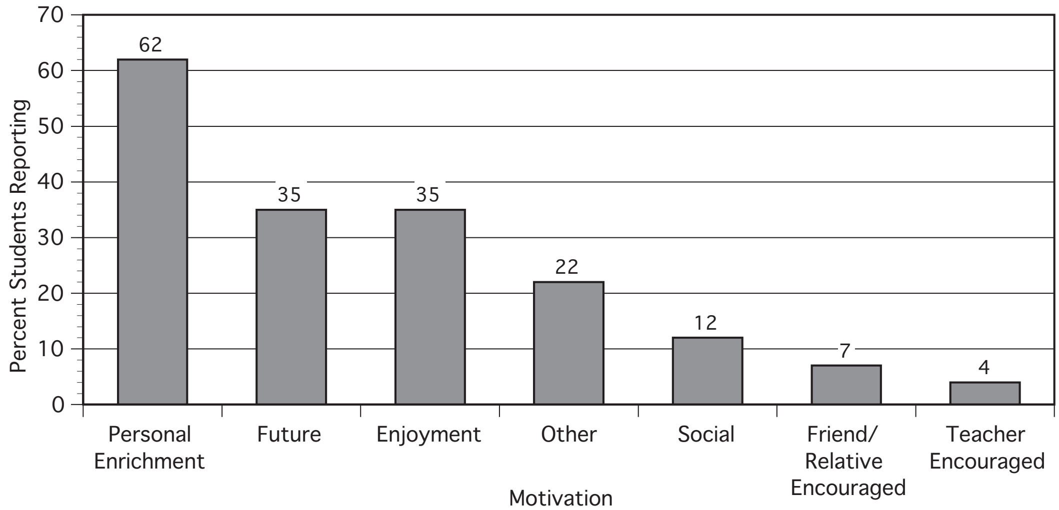
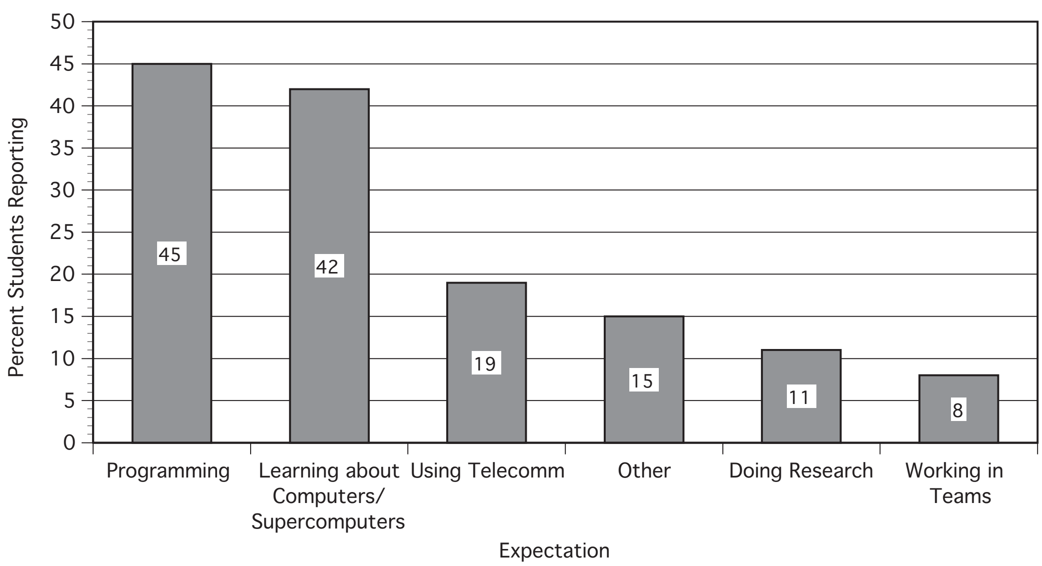


Figure 28
Student Expectations of AiS Class
n=182
(multiple responses possible)



Students could cite more than one reason for enrolling in the course and therefore could receive more than one motivation code; the mean number of motivations cited per student was 1.82 .

Almost two-thirds (62%) of students indicated that they joined AiS to enrich themselves personally — to learn more about something of interest to them. Nearly a third of the students (35%) stated they enrolled in AiS because they thought it would be fun, and another third (35%) said they thought that it would help them in the future. Twenty two percent (22%) of students mentioned that other factors, such as participating in the program last year and not being interested in other courses offered at the same time as AiS, influenced their decision to become involved in the AiS program; 12% cited social reasons for taking the class. See Figure 27 for a summary of student motivations.

In articulating reasons for their enrollment in the AiS program, female students indicated both intrinsic and extrinsic motivations, whereas male students tended to be largely self-motivated. It is notable that 62% of girls reported that teachers encouraged them to join the class and that social factors influenced their decision to become involved in AiS.

Expectations. Student expectations of the AiS course were broken down into six categories: learning about computers and supercomputers; programming; using telecommunications; doing research projects/developing problem solving skills; working in teams; and other. Again, multiple codes could be assigned to journal entries; the mean number of expectations per student was 1.42.

In response to the question *"What did you expect the class to be about?"*, almost half of the students (45%) answered programming. Another 42% indicated that they thought they would the course would be about computers or supercomputers. Nearly a fifth (19%) of AiS students expected the class to be about using telecommunications; 11% expected to do research projects in the course; and 8% noted that they thought the class would be about learning to work in teams. Older students were more likely to expect to conduct research in their AiS classes than younger ones. No freshmen and only 4% of sophomores reported this expectation whereas 17% of both juniors and seniors articulated it.

Fifteen percent (15%) of the students also mentioned that they had other expectations. These included thinking that the class would be easy and thinking it would be about a specific subject, e.g. math or physics. See Figure 28 for a summary of student expectations.

Selection and characterization of preliminary project topics. In the second set of journal questions, students were asked to describe their project topics and to reflect upon how they selected particular research subjects. 65% (n=167) of students responded to these inquiries. Their project topics were characterized by subject area: Computer Science; Social Science; Biology/Medicine; Ecology/Agriculture; Physics; Astronomy Mathematics; Engineering; Earth Science; Chemistry; and don't know. Methods of selecting projects and influences on topic selection were coded according to closed-ended categories which students checked off in their journal responses.

Project topics. The highest percentage of students (20%) indicated that they planned to investigate some phenomenon related to Earth Sciences — meteorology, geology, climatology, etc. Most common among earth science topics were those involving weather, earthquakes, and the ozone layer. Nearly a fifth of the students (18%) stated that their projects were related to physics, i.e. involving light, sound, mechanics, or the calculation of forces, velocities, etc.

Fourteen (14%) of AiS students reported that they were developing engineering projects, and 11% suggested that they were working on biomedical or mathematics projects. Topics coded as engineering ranged from analyses bridge strength and structure to examinations of the aerodynamics of paper airplanes. Examples of biomedical subjects include: an investigation of the effects of growth hormones on animals; a genetic study of hereditary diseases; and research on dolphin communication. Mathematics projects generally involved fractals or statistics.

In a significant shift down from last year, only ten percent (10%) of students described their projects as being related to astronomy. At the same time last year, 23% of students indicated that they were developing astronomy projects. The subject matter

Figure 29
Preliminary Project Topics
n=167

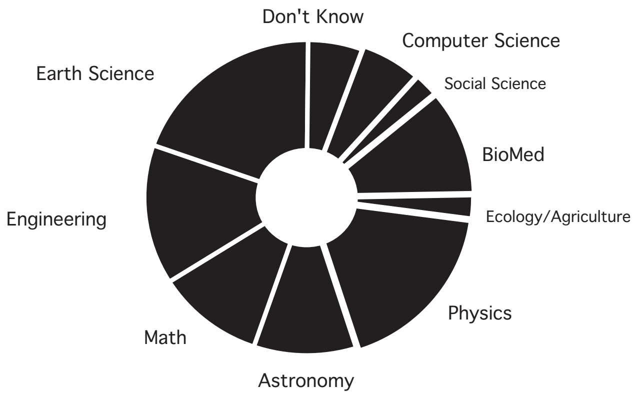


Figure 30
Selection of Preliminary Project Topics
n=166
(multiple responses possible)

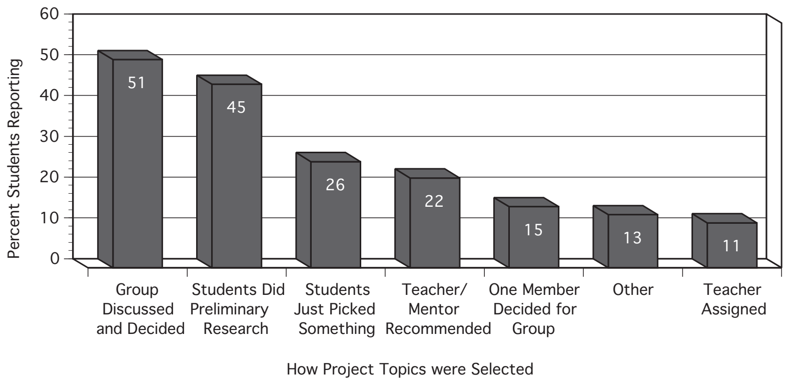
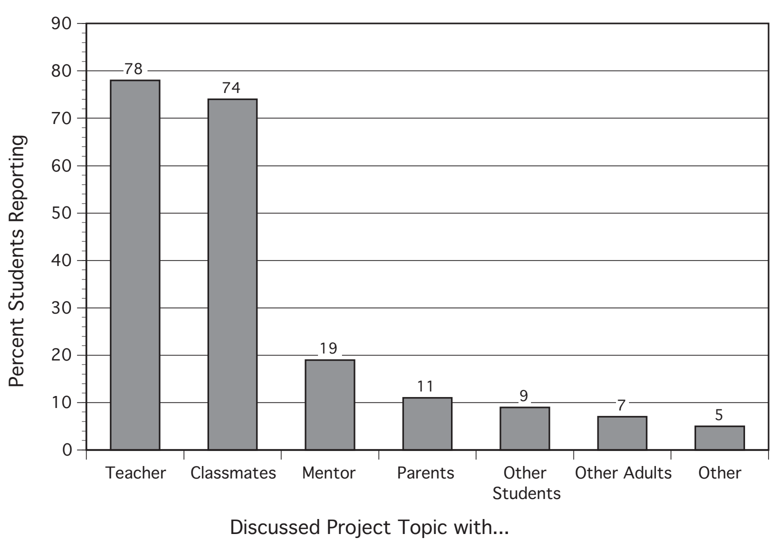


Figure 31
Influences on Topic Selection
n=167
(multiple responses possible)



of astronomy projects was consistent with last year: black hole or supernova simulations; analyses of comet orbits; and planetary travel.

Six percent (6%) of topics were computer science oriented (artificial intelligence, interface design, etc.), and 2% were predicated upon the social sciences, e.g. economics and psychology. Five percent (5%) of students had not decided upon a project topic by the end of October (see Figure 29).

Gender differences in the types of preliminary project topics that students selected were present to a slight degree. Biomedical topics were chosen mostly by females; nearly two-thirds of students who selected biomedical project topics were female (16% of all girls). All of the students who selected computer science project topics were male. Among students who selected physics topics (18% of all students), half were female and half were male. Similarly, male and female students chose earth science topics in nearly equal proportions.

Topic selection. To select these project topics, just over half of AiS students (51%) reported discussing the subjects in their groups; nearly half (45%) also conducted preliminary research before deciding upon the topic. About one fourth of the students (26%) reported that they just picked something, and another fifth (22%) reported that their teacher or mentor had recommended their project topic. Fifteen percent (15%) of students stated that one member had made the decision for the whole group, and 3% cited other factors. Only 11% indicated that their teacher had assigned the project topic (see Figure 30).

In answer to the question “Who did you talk to about your project?,” over three-fourths (78%) of AiS students noted that they had discussed their topic with their teachers. Nearly three-fourths (74%) indicated that they also talked about their projects with their classmates. About a fifth of students (19%) reported speaking with their mentors about project ideas, and 11% involved their parents in discussions about AiS project topics (see Figure 31).

Classroom use of computer resources and selection/characterization of initial project groups. Near the middle of their first semester experience, students were questioned about their use of computer resources in the classroom and about their project groups. 56% (n=144) of students queried responded to two closed-ended (check box) questions and two open-ended questions about these subjects (see Table 11).

Table 11

Question	**Possible Answers:**
1. Which of the following computer resources are you using EVERY WEEK in your AiS class? (Check all that apply.)	• Programming (FORTRAN or C) • Visualization (SpyGlass, Wireman) • Data Analysis (ClarisWorks, other spreadsheets) • Research (Mosaic, Gopher, Veronica, Archie, BBSs, on-line libraries) • Communications (E-mail, chat) • Other (Please specify.)
2. Tell us how your project or the way you worked on your project would change if you did not have access to a computer.	• Open-ended
3. Are you working alone or in a group? If you are working in a group, who are the other members of your team?	•Open-ended
4. If you are working in a group, did you: (Check only one.)	•Select your own group? •Get assigned to a group by your teacher? •Other (Please specify.)

Classroom use of computer resources. Almost all students reported that they used programming (94%) and communications (92%) resources at least once a week in their AiS classes. Three fourths of the students (76%) also noted weekly use of computer research capacities — Internet-wide services such as NCSA Mosaic and Gopher as well as BBSs and on-line libraries. About half (42%) used data analysis resources, e.g.. spreadsheets, and a fifth (21%) of students indicated they used visualization tools like SpyGlass and Wireman on a weekly basis (see Figure 32).

Role of computers in preliminary project work. Student answers to Question 2 were coded into eight categories: Programming (for calculation and prediction); visualization; data analysis; research; communications; efficiency; data presentation; and don't know. Responses marked as *efficiency* included comments suggesting that computer use enabled students to deal with more data and to do so in a shorter amount of time. *Data presentation* differed from other categories in its focus on how the data looked, e.g. "we wouldn't be able to make our project look nice and neat" and "we would not be able to...do nice graphs."

Using computers to collect data/do research (36%) was the most common way that students reported having used computer resources in their project work. A substantial number of students (32%) also reported that computers allowed them to work more efficiently on their projects, e.g. "My work would be a little bit harder to do if I did not have access to a computer;" and "The project would develop much slower...and the quality of the project would degrade." Only 25% of students indicated that they used programming in their project work, and 12.5% said their projects made use of communications and data presentation aspects of computing (see Figure 33).

Initial project groups. Most students in this sample were working on their projects in groups; only 6% report that they were working alone. The greatest number of student groups include both males and females (38%). However, 35% of groups were all male, and 21% were all female groups. Three person (30%) and four person (29%) groups were the most common among student groupings. About a fourth (22%) of AiS students worked in pairs, and 7% worked in groups of five. Six percent (6%) of students were members of groups that consisted of more than five people (see Figures 34 and 35).

Selection and characterization of project mentors. Halfway through the AiS curriculum (in mid-December for full year students), students were queried about their experiences finding and communicating with mentors. Students were asked to characterize their mentors according to profession and relation to self or teacher, to indicate how often they communicated and desired to communicate with mentors, and to discuss what kind of assistance they would like to receive from mentors.

Characterization of project mentors. Among the 56% of the students who responded to these questions, roughly half (52%) had mentors; the other 48% did not have mentors. It was most common for AiS mentors to be professors or scientists; 38% of the students reported that their mentors fell into this category. Eighteen percent (18%) of students said that their mentors were professionals in the community, and ten percent (10%) enlisted family members as mentors. Five percent (5%) of AiS students identified a teacher as their mentor, and 4% indicated they were mentored by another student. This category included high school, college, and graduate students. 24% of students indicated that they did have mentors but provided no further information. See Figure 36 for a summary of this information.

When data about AiS student-mentor relationships was analyzed by sex, it was clear that a disproportionate number of male students had no mentor. 69% of female students, compared with 40% of male students, reported that they had a mentor in December. Among these students, more females (67%) than males (33%) indicated that their mentor was a professor or scientist.

Figure 32
Weekly Use of AiS Classroom Computer Resources
n-144

(multiple responses possible)

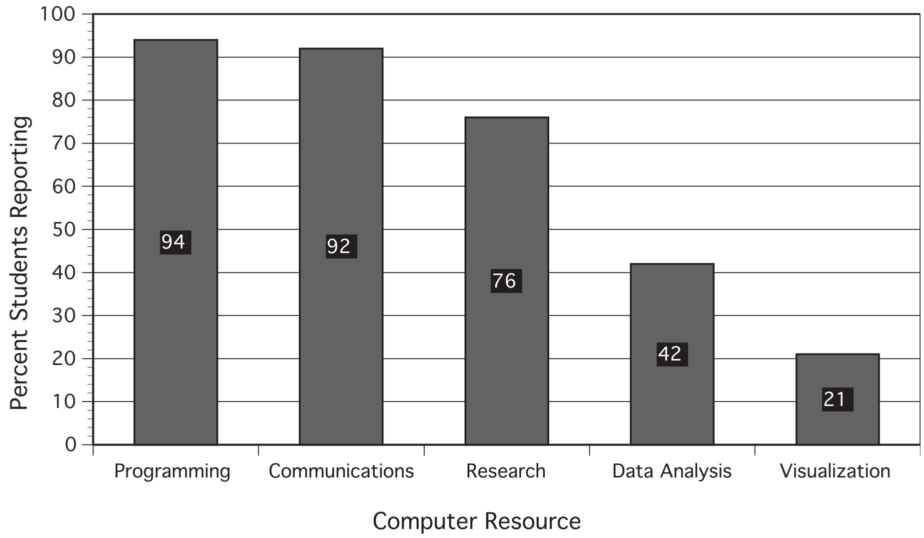


Figure 33
Role of Computers in Early Student Project Development
n=144
(multiple responses possible)

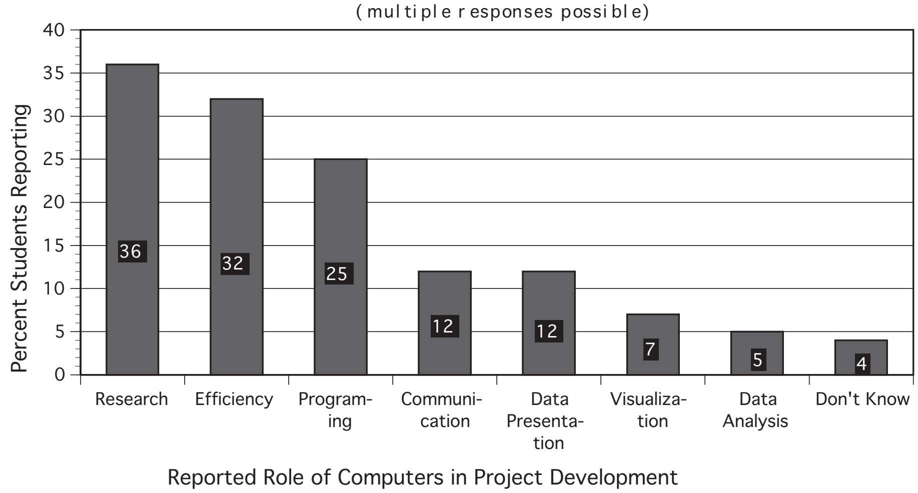


Figure 34
Composition of Initial Student Groups
n=143

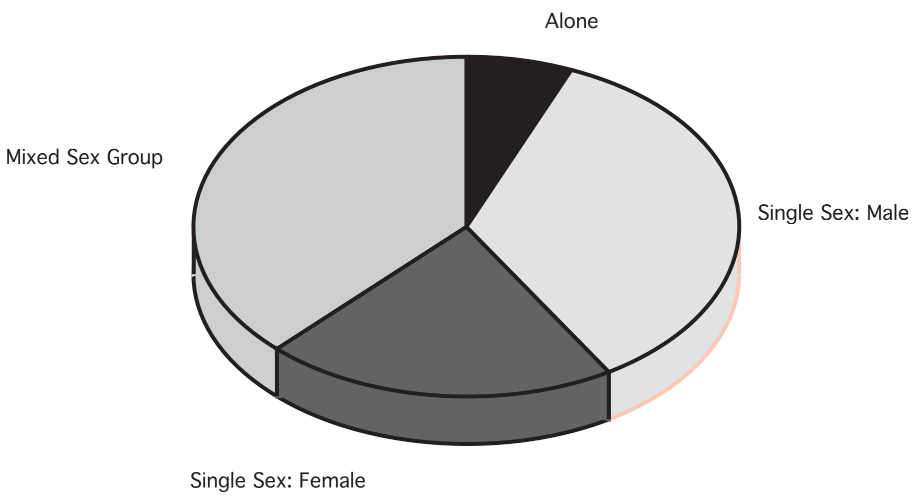


Figure 35
Size of Initial Student Groups
n=143

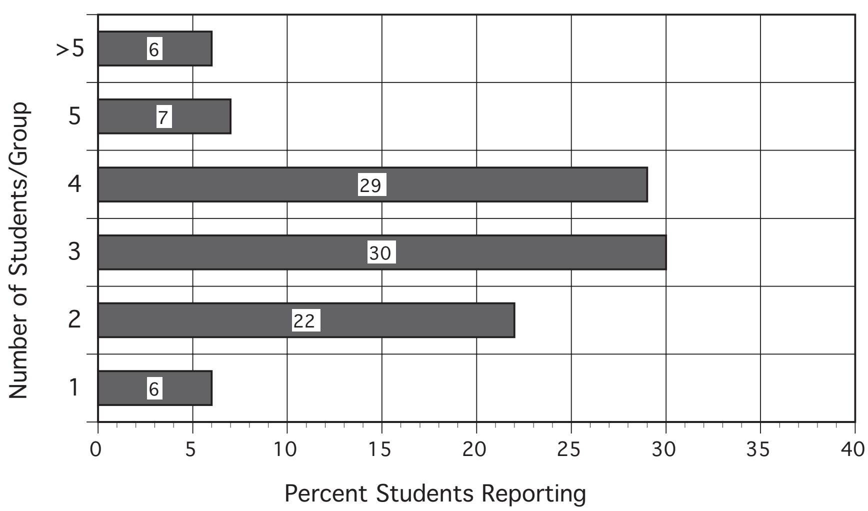
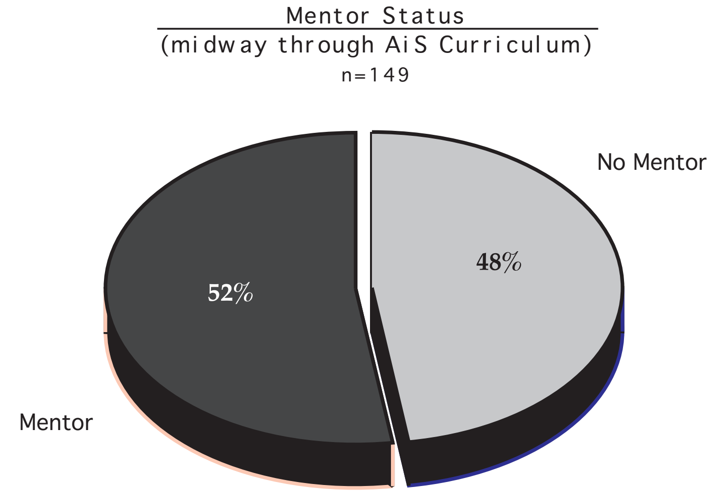


Figure 36


Mentor Status
(midway through AiS Curriculum)
n=149
No Mentor
48%
52%
Mentor

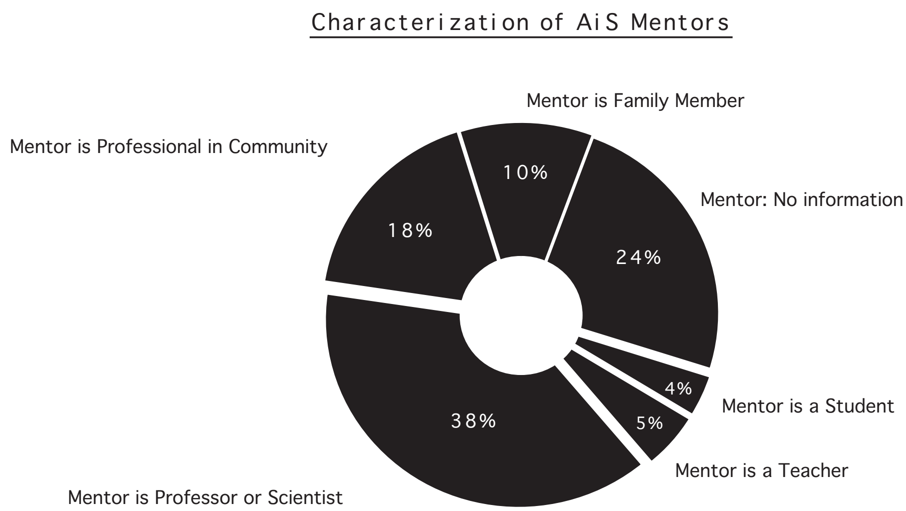

Characterization of AiS Mentors
Mentor is Family Member
Mentor is Professional in Community
10%
Mentor: No information
18%
24%
4%
Mentor is a Student
38%
5%
Mentor is a Teacher
Mentor is Professor or Scientist

Figure 37
Frequency of Early Student Communication with AiS Mentors:
Actual vs. Desired in December

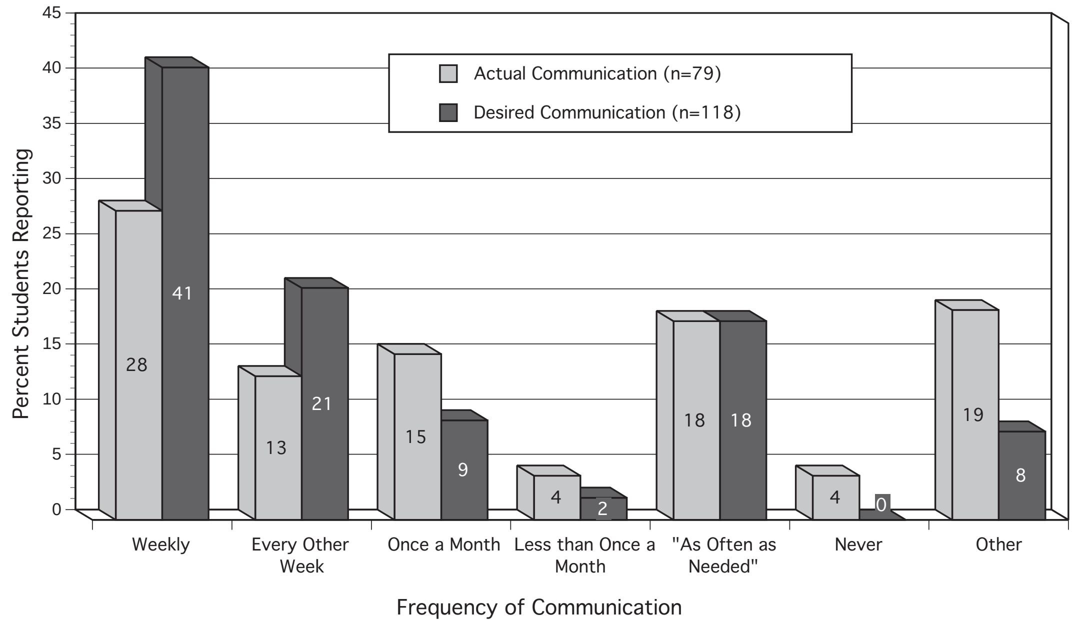
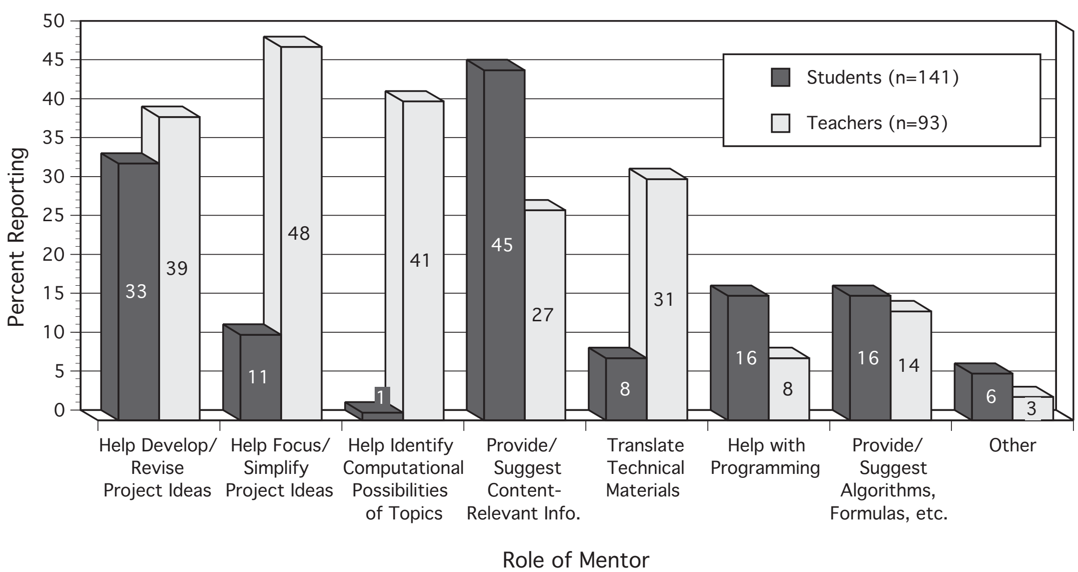


Figure 38
Role of AiS Mentors: Comparison of Student vs. Teacher Descriptions



Student contact with project mentors. Although most students *desired* frequent contact with their mentors (weekly (41%) or biweekly (21%) less than a third (28%) reported that they communicated with their mentors every week. Only 13% communicated every other week. 15% of AiS students were in contact with their mentors on a monthly basis, and 18% communicated "as often as needed." A handful of students (4%) indicated that they communicated with their mentors less than once a month or that they had never met their mentors. About a fifth (19%) of the students indicated that they communicated with their mentors at other frequencies, e.g. everyday, when the mentor was available, when it was convenient, etc. See Figure 37 for a comparison of desired vs. actual frequencies of AiS student-mentor communication.

Role of project mentors. Finally, students were asked to describe the kind of assistance they would find most valuable to receive from a mentor. Their responses were coded according to categories used in the teacher survey. These categories are: (1) to help develop and revise project ideas; (2) to help focus or simplify project ideas; (3) to help identify computational possibilities of project topics; (4) to provide or suggest content-relevant information; (5) to translate technical materials and ideas; (6) to help with programming; (7) to provide or suggest algorithms, formulas, or programs; (8) to make facilities/resources available; and (9) to review and provide feedback on student projects. In their journal comments, students may have listed many of these roles, thus they were able to receive multiple codes for this question.

Among students, the most frequently cited roles for AiS mentors were to provide or suggest content-relevant information (45%) and to help develop and revise project ideas (33%). Help with programming (16%) and providing or suggesting algorithms, formulas, etc. (16%) were listed by less than a fifth of the students. 11% of students suggested that mentors could help them focus or simplify their project ideas, and 8% indicated they would like mentors to translate technical materials and ideas for them (see Figure 38).

Results: Second Semester

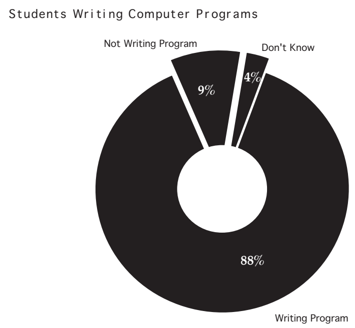
Integration of programming and visualization techniques into project work. At the beginning of the second semester, students were queried about how they were integrating programming and visualization into their AiS projects. They were asked to indicate whether they were writing a program as part of their project and to describe its input, output, and function. Sixty-one percent (n=143) of students responded to these questions.

Their responses were coded according to how clearly they could describe each of these components. *Clear descriptions* of input, output, and function included comments such as:

> [The program] will determine how long of a solar sail we will need in order to go to mars within a lifetime of a human. [Input] – the angle and solar thrust. [Output] – the size and angle needed for the solar sail.

> It will tell the distance 2 dolphins can be apart and still communicate. [Input] – Salinity of the water, speed the dolphins are traveling, topography of the ocean, and speed of the

Figure 39
Integration of Programming into AiS Projects
(n=143)



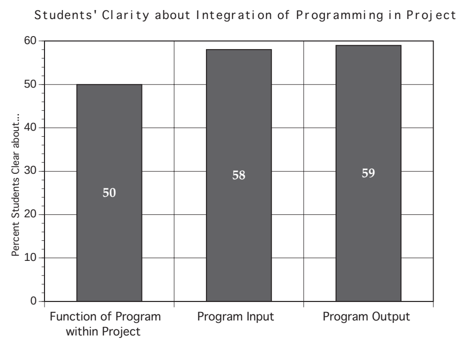
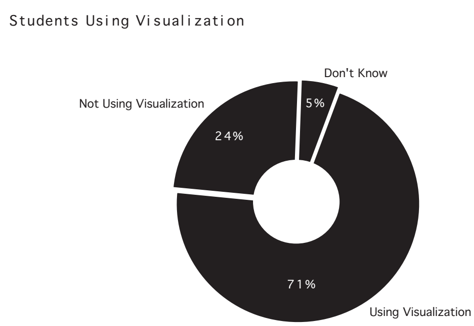
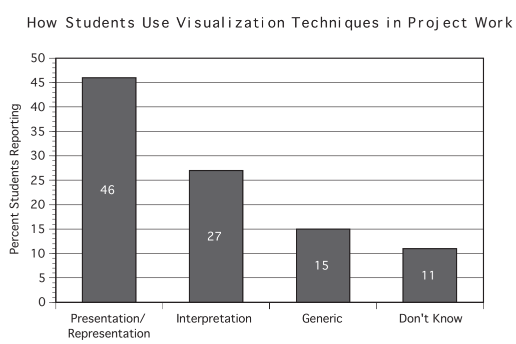


Figure 40
Integration of Visualization into AiS Projects
(n=143)





multiple responses possible

> currents. [Output] — It will tell the distance 2 dolphins can be apart and still communicate.
>
> My project (if completed) will find the energy needs of a community and its available energy sources through given demographics, and it will produce a system of analysis that shows that combined alternative energy systems are more safe and efficient than conventional energy sources. The input will exist in a user-environment. In this user-environment all the given data for a certain community will be retrieved from the user (i.e., population, energy consumed, energy available, etc.). The output will be an outline or plan that can show alternative energy's significance to a community and how it can be integrated into that community.

Unclear descriptions included:

> [The program will] solve our problem. [Input] — certain figures. [Output] — certain figures.
>
> The program will compute certain equations in which we will learn more about fractals and the butterfly effect. [Input] — Numbers which can serve as weather patterns to prove the butterfly effect. [Output] — will serve to prove that our hypothesis is correct, and the butterfly effect does occur.
>
> I expect my computer to help change the numbers using a visual spyglass. The input will be all the raw material and research that we have. The output will be the results that we receive.

Students were also asked if and how they were using visualization tools within their projects. Explanations of how students used visualization fell into four categories:

(1) Don't know;
(2) Generic (e.g., "Visualization of data," or "It is vital to the effectiveness of our project. Our project will consist of, in percentages of importance to us, 50% program and 50% visual aid," or "It will show time in a graphical manner.");
(3) Used to represent or present data (e.g., "It will show the density of an area on a grid by color representation," or "[It will be a] 3d map that shows current combined with efficiency," or "It will show what the debt will do on a chart.");

(4) Used to help interpret or better understand data (e.g., "Hopefully it will give our group members a better concept of how well our program predicts the temperature of the spacecraft at a given time, as well as point out any blatant errors...," or "It will allow me to see how the lifeforms evolved, relative success of certain adaptations, and generally tell me something about the data," or "[It will] help the user understand how we got to the planet and why it was the best route."

<u>Integration of Programming</u>. Almost all students (88%) noted that they were writing a program for their AiS projects. Nine percent of students (9%) stated that they would not complete a program for their project, and 3% were unsure. Of the students who planned to include a program in their work, only half (50%) were able to specify what its function would be within the context of their projects. Approximately three-fifths (58%) of students could clearly describe their programs' input and output (see Figure 39).

<u>Integration of Visualization</u>. Seventy-one percent (71%) of students were using visualization in their projects, and 5% thought they might use these techniques but were still unsure. Among those students who were using visualization, the greatest percentage (46%) reported that its purpose in their projects was to represent or present data. Twenty-seven percent (27%) indicated that they used it to help themselves understand or interpret the information (see Figure 40).

Project questions and uses of computing. In February, students were asked about questions that had emerged during their project work and about how they were using computers to answers these questions. Fifty-four percent of students in the journal sample (n=125) commented on these issues. Their responses both questions were assigned multiple codes when appropriate.

Consistent with last year's coding, student questions represented five themes: questions about content; questions about programming; questions about logistics; no questions; and don't know. Content questions included those about background information as well as interpretation of data and conclusions. Programming questions centered upon issues of learning FORTRAN or C, debugging code, or working with certain hardware configurations. Logistic questions generally involved concerns about jump-starting the project, finishing it on time, or getting everyone in the group to work together. Other questions were mostly about the validity and value of projects in larger society.

Figure 41
Types of Student Project Questions
n=125
(multiple responses possible)

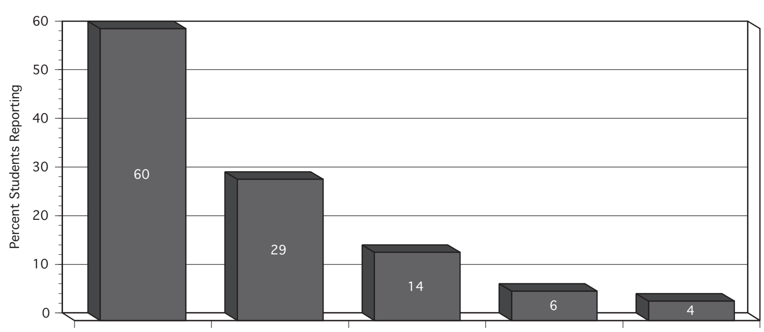
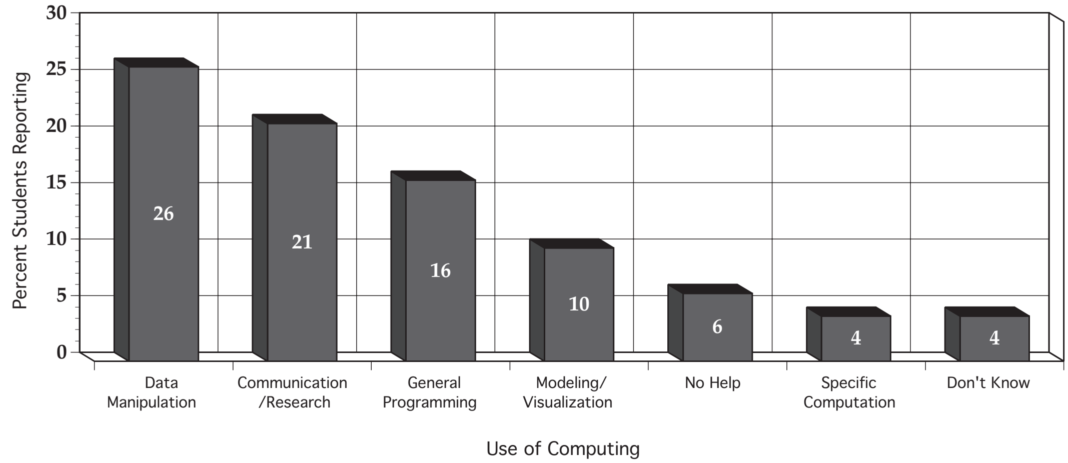


Figure 42
How Students Use Computing to Answer Project Questions
n=125
(multiple responses possible)



Students suggested that they used computing in a number of ways to help solve their project questions. Their responses included: general programming; specific computations (those which mentioned the calculation of precisely identified values); data manipulations which focused on the computer as a means to calculate unspecified values, to solve equations, or figure out relationships between variables (but which did not mention programming); modeling/visualization; and communication/research. Additionally, some students reported that they just did not know how computers would help; others indicated that computers would be of no help in solving their project questions.

Project questions. A majority of AiS students (60%) reported that they had content questions in February. Another 29% had logistical questions and 14% said they had questions about programming. Six percent (6%) of students had questions that fell into the category of "other," and 2% of students either did not know what questions they had or had no questions at all (see Figure 41).

Use of computing to answer project questions. To help answer these project questions, the greatest number of students (26%) stated that they used computing for data manipulation. Among responses that fell into the data manipulation category were: "It will calculate the answers that we need for our project;" and "The computer can iterate the equation many times to get an accurate result." Twenty-one percent (21%) noted that they used communication/research functions of computing, and 16% referred generally to programming. Ten percent (10%) of AiS students reported that they used computers to model or visualize their project data, and 6% said that computers were of no help to them in answering project questions (see Figure 42).

Examination of journal responses by student sex revealed that male and female AiS students employed computer resources in slightly different ways to answer their project questions. More girls (36%) than boys (19%) indicated that they used the computers for communication and research purposes . However, fewer girls (7% compared with 17% of boys) reported using the computer to visualize or model project phenomena.

Second or third year AiS students were also more likely to use computers for modeling and visualization (29%) than their first year counterparts (8%). They were also less likely to use the machines for data manipulation (12% vs. 38%).

Project difficulties and student-mentor interactions. In March, students were asked to reflect on two different aspects of their AiS experience: they were requested to describe the difficulties they had encountered in their project work, and they were asked a series of closed-ended questions about their mentor interactions. Fifty-one percent of students (n=118) provided insight on these aspects of project development.

Project difficulties were coded according to eight themes: (1) programming; (2) computation — having to do with developing, finding and using algorithms/formulas; (3) understanding; (4) finding information relevant to project topics; (5) mechanics (e.g., making the presentation look good or typing the code); and (6) mentor relationships. Additionally, students could report that they had no difficulties or that they had “other” problems, such as constructing physical models or manually collecting certain types of data. Table 12 provides examples of common classes of difficulties mentioned by AiS students.

Table 12

Project Difficulty	Tell us what’s most difficult about your project... (Sample Responses from Student Journals)
Programming	“Finding out how to write a program in FORTRAN to answer the problem.” ”The most difficult part of the project is probably all of the programming that is needed to accomplish what is needed to be accomplished. It is very difficult to figure out how exactly to start and finish programming.”
Computation	“...finding out what each variable in our equation represents...” ”Increasing the precision of our answer.”
Understanding	“The vast amounts of information we had to sift through (and continue to sift through) in order to create a background for our project.” ”The most difficult part is figuring out exactly what our project is about and how it will be used.”
Finding Information	“Finding all the mathematical equations that I need to complete my project.” ”Finding information that is understandable.” ”Finding appropriate data.”
Mechanics	“getting the visualization to look good.” ”figuring out how to incorporate the graphics...”
Mentor Relationships	“getting a mentor to help us!”

Closed-ended journal responses about mentor relationships were coded according to the categories specified in the original questions. Answers to the question about the role of mentors in project work, however, were analyzed using a standard set of criteria developed for the teacher survey and also used in coding November journal responses about desired mentor role.

Project difficulties**.** AiS students in the journal sample reported most commonly (52%) that they had difficulties with programming; 22% also expressed difficulty in finding relevant information. Twenty percent (20%) indicated that they had trouble with the algorithmic/formulaic component of their projects, and 13% had trouble understanding the information they did find. Twelve (12%) of students mentioned “other” difficulties such as manually collecting certain types of data. Less than a tenth of students indicated that they had difficulty with project mechanics (7%) and mentor relationships (3%). Only 1% of students said they had no difficulties (see Figure 43).

1994-95 data on project difficulties differ quite a bit from difficulties reported by students in 1993-94. Most notably, AiS students this year reported having far fewer problems with mechanical, computational and understanding aspects of project development. However, programming difficulties were more prevalent this year than last. See Figure 43b for a comparison of data from 1994-95 and 1993-94.

Figure 43
Project Difficulties
n=118
(multiple responses possible)

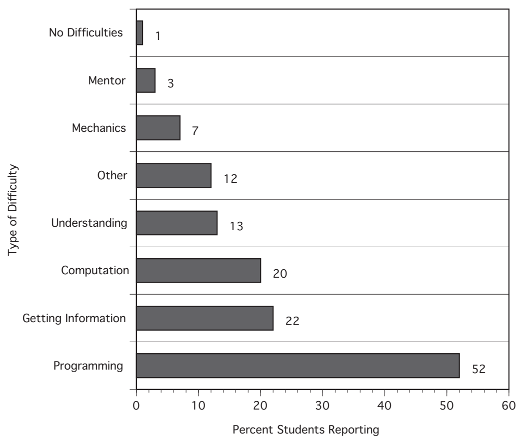


Figure 43b
Comparison of Student Reported Project Difficulties
1993-94 vs. 1994-95
(multiple responses possible)

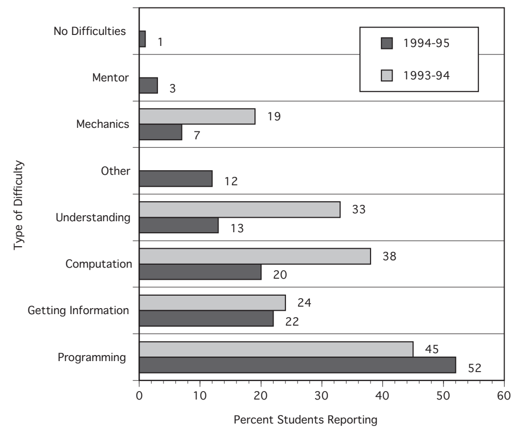
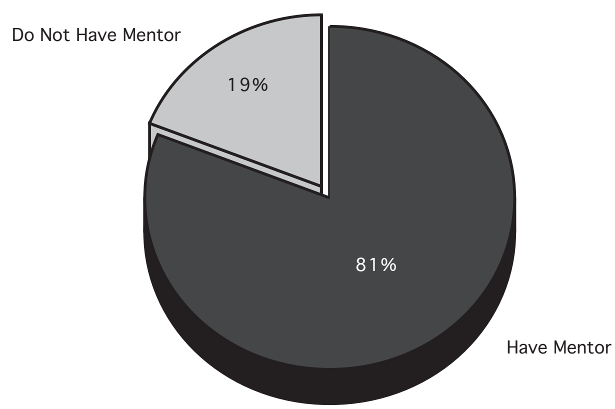


Figure 44
Student-Mentor Interactions

Presence of Mentor
n=118



Frequency of Communication with Mentor (in March)

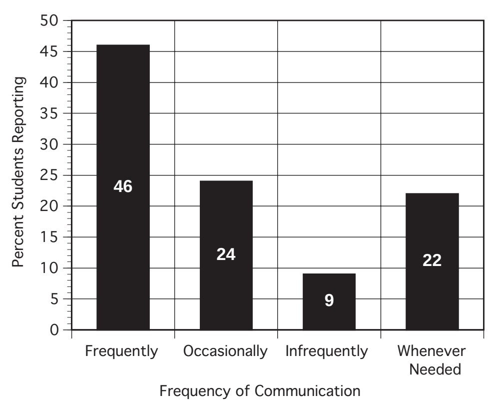


Figure 45
How AiS Students Found their Mentors
n=118

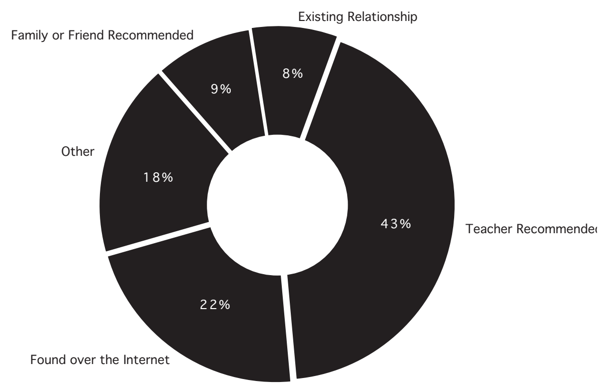


Figure 46
Role of Mentors in Project Work as Reported in March
n=118
(multiple responses possible)

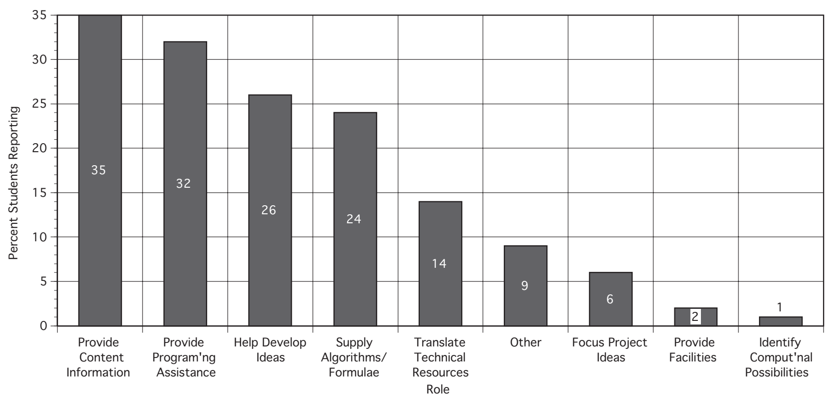
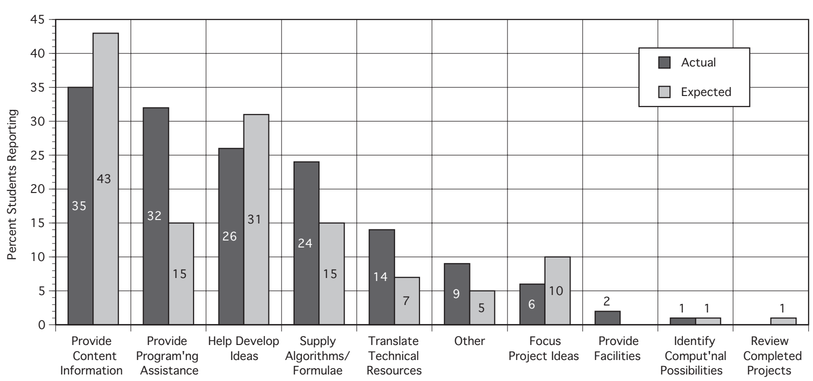


Figure 47
Comparison of Mentor Roles
Actual (reported in March) vs. Expected (reported in December)
(multiple responses possible)



Journal responses also suggested that male and female students perceived and/or faced different types of challenges in developing AiS projects. Girls (65%) more than boys (47%) reported having trouble with programming aspects of their project work. Female students also noted more often that they experienced difficulty in finding information appropriate to their project topics; 27% of girls compared with 18% of boys specifically mentioned this challenge. This latter finding may related to the project topic they selected. Overall, however, female students did not report significantly more problems than males (the mean number of difficulties for girls was 1.4; for boys, it was 1.2).

Mentor interactions. Over three quarters (81%) of AiS students reported that they had a mentor in March, compared with 52% in December. Of these students, 46% communicated with their mentors frequently — daily or 1 or 2 times per week. Another 24% communicated with their mentors occasionally (biweekly or once a month), and 9% of students had infrequent contact with their mentors which amounted to less than one communication per month. About a fifth of the students (22%) said that they communicated with mentors "whenever needed" (see Figure 44).

The highest proportion of students (43%) found their mentors through the help of a teacher. About a fifth (22%) reported that they obtained their mentors through the Internet, and 18% acquired their mentors through "other" mechanisms, such as asking for assistance at the local industrial plant or "making a few phone calls." Nine percent (9%) of mentors were recommended to students by their friends or family, and 8% were already affiliated with students as family members or existing friends (see Figure 45).

Mentor assistance**.** Students noted that their mentors assisted them in a variety of ways, but primarily by providing content information and programming advice. Thirty-five percent (35%) of students reported that their mentors helped them by supplying content material, and 32% said their mentors helped with programming. Nearly a fourth of students articulated that mentors assisted them in developing project ideas (26%) and by supplying algorithms or formulas (24%). Fourteen percent (14%) got help from their mentors in translating technical materials and ideas into lay person's language, and 6% said their mentors helped focus project ideas. Nearly a tenth of students (9%) indicated that their mentors helped them with other tasks, namely "answering questions." See Figure 46 for a summary of how mentors actually assisted students in their project work; see Figure 47 for a comparison of expected and actual assistance provided.

There were some differences in the ways students described the role of mentors in their project work. Female students were more likely (30%) than males (15%) to report that their mentors helped them develop and enhance their project ideas. First year AiS students (25%) reported more often than their more experienced peers (10%) that their helped them develop and enhance their projects. Similarly 21% of inexperienced AiS students noted that they received help in translating technical ideas and materials; 10% of second or third year AiS students made this comment.

Project changes and their causes. A few weeks prior to their Expo presentations, students were asked to think back upon the changes they had made in their projects since mid-year and the causes of these changes. Forty-two percent of students (n=97) responded, marking selections which applied from a closed-ended list of possible changes. This list included major changes such as group composition, mentored status, and project topic as well as more minor changes such as FORTRAN code, project questions, content, and programming.

The causes of change were represented by nine codes: (1) pragmatics; (2) issues involving group collaboration; (3) acquisition of more knowledge; (4) lack of

Figure 48
Project Changes since Mid-Year
n=90
(multiple responses possible)

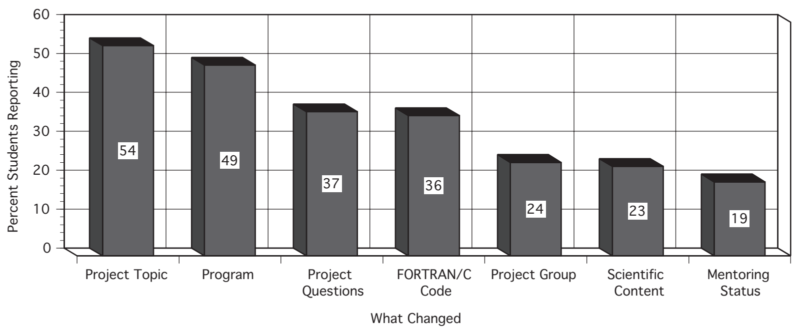
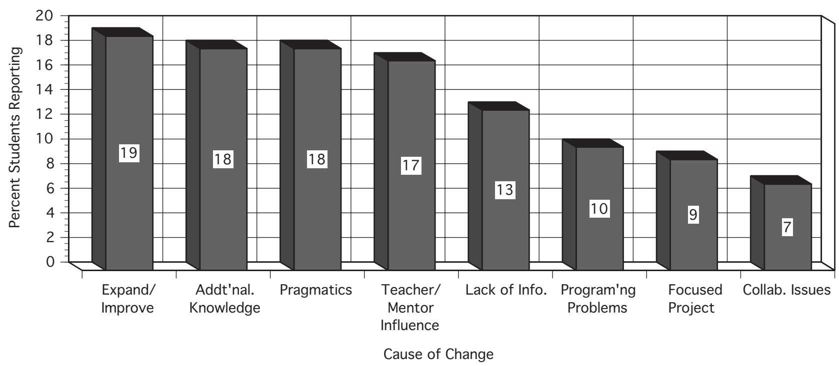


Figure 49
Causes of Project Changes
n=90
(multiple responses possible)



information; (5) programming problems; (6) general expansions or improvements; (7) mentor or teacher influences; (8) more focus; and (9) other.

<u>Project changes</u>**.** Over half (54%) of students reported that they had changed their project topic since mid-year, and 49% said they had changed their program. Over a third indicated that they had modified their project questions (37%) or their code (36%), and nearly a fourth had changed project group (24%) or content (23%). Nineteen percent (19%) of AiS students had experienced a change in mentoring status since mid-year (see Figure 48).

The total number of changes that students reported varied from zero to seven. Thirty-one percent (31%) reported two changes, 27% indicated having made one change, and 22% of students said they had made three changes in their project since mid-year. Five percent (5%) experienced four changes, and 10% of students described five or more changes.

<u>Causes of changes</u>. Positive factors were listed most frequently as contributing to project changes, with 19% of students indicating that they had expanded or improved their original projects and 18% suggesting that they had acquired additional knowledge which altered their projects. Another 18% of students cited pragmatic reasons for changing their projects, and 17% noted that teacher or mentor influence had been a cause of change. Negative factors such as lack of information (13%) and programming problems (10%) also contributed to the changes students made in their projects since

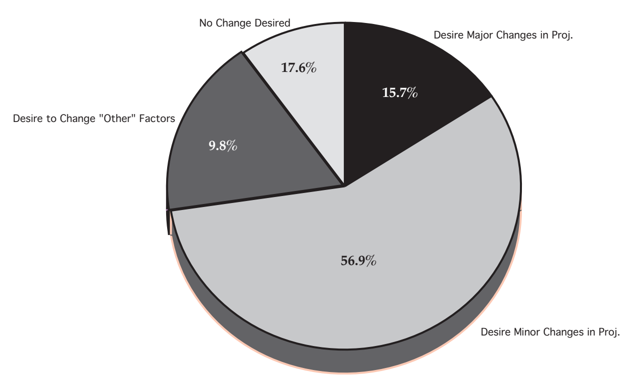
mid-year. Less than 10% of students reported that focusing project topics (9%) or collaboration issues (7%) had influenced their project changes (see Figure 49).

Student self assessments. After the flurry of Expo had passed, students were asked to reconsider their projects and comment on what they would like to do differently if given the opportunity. Responses from 44% of students (n=102) fell into four categories: (1) make major changes such as choosing different project or different group; (2) make minor changes, i.e. simply tweaking the existing project; (3) no changes; and (4) other. "Other" responses most often involved investment of effort, Expo judging circumstances, or mentoring situations. Issues of time management, presentation, and complexity of project prescription also seemed to emerge consistently among student responses and were accounted for accordingly.

<u>Self-assessment</u>**.** Most students (57%) reported that they were satisfied with their projects overall and would only like to make minor changes. Eighteen percent (18%) of students suggested that their projects were fine and needed no change; 16% stated that they would like to have made major changes in their projects. Ten percent (10%) of AiS students indicated that they would like to change "Other" factors about their projects.

In descriptions of how they would like to change their projects, over half of students (52%) suggested they would like to increase the complexity of their projects Nearly a third (32%) indicated they would like to improve project presentations, and 30% noted that they would like to have managed their time more efficiently, e.g. "I would have started earlier...." (see Figure 50.)

Figure 50
Student Self-Assessment
n=102



Discussion

Learning process data collected throughout the year help to tell the story of how students experienced the AiS program. These data suggest that students entered AiS for a variety reasons, but that female students more often than males indicated that a teacher or friend invited them to join the class. Similarly, young people entertained a number of expectations about the course. Most expected the class to be about computers and programming. As was the case last year, however, a persistent minority of students did enter the course thinking they would develop research projects during the year.

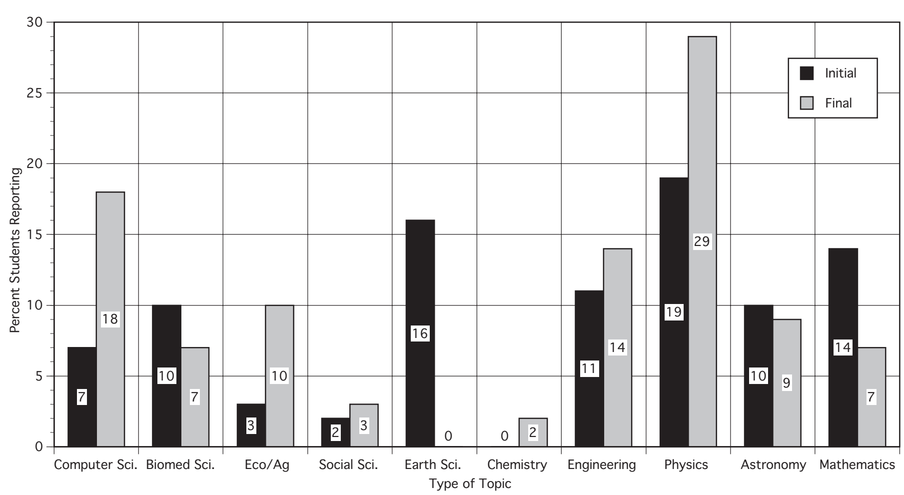
Students were most likely to select preliminary project topics related to physics, earth science, and mathematics. By the end of the year though, over half of journal-writing AiS students had changed their project topics with many shifting to topics involving computer science and ecology/agriculture. Physics projects continued to dominate the stage of AiS in both the fall and spring. For a comparison of preliminary and final project topics for the sample of students that was videotaped, see Figure 51.

Early in the year, students appeared to make extensive use of programming and Internet research and communication capacities. It was not clear, however, that they recognized the connections between their programming activities and their project work. This trend continued. By January, an overwhelming proportion students suggested that they were writing computer programs, though only half could clearly describe the function of their programs within the context of their projects. This finding, however, represented an improvement over last year when only one third of students expressed clarity about the role of programming within their projects.

Though questions about scientific content dominated in January, by February, a majority of students indicated that they were having the most difficulty with programming aspects of their project work. This finding paralleled data about the expected versus actual role of mentors in project development. Early in the year, students expected their mentors to provide content information; programming assistance was anticipated but to a much lesser extent. At the end of the year, however, students were equally likely to have received help with scientific content as they were to have gotten assistance in writing and debugging their programs. Additionally, mentors appeared to provide substantial aid in developing project ideas and in supplying necessary algorithms and formulas.

Data about the ways in which mentors help students develop and expand their AiS projects may be very telling, since both students and teachers repeatedly cited the mentoring experience as a key aspect of AiS. Supported by data about project changes and desired changes (self-assessments) — over half of AiS students changed their project topics during the second semester and more than 50% also indicated that if given the opportunity, they would like to increase the computational complexity of their projects — these findings suggest that defining appropriate computational project topics and translating scientific content into computational models and computer programs continue to present the biggest challenge to students and teachers in the AiS program.

Figure 51
Comparison of Student Project Topics
Initial (October) vs. Final (May)



Student Project Presentations

Method

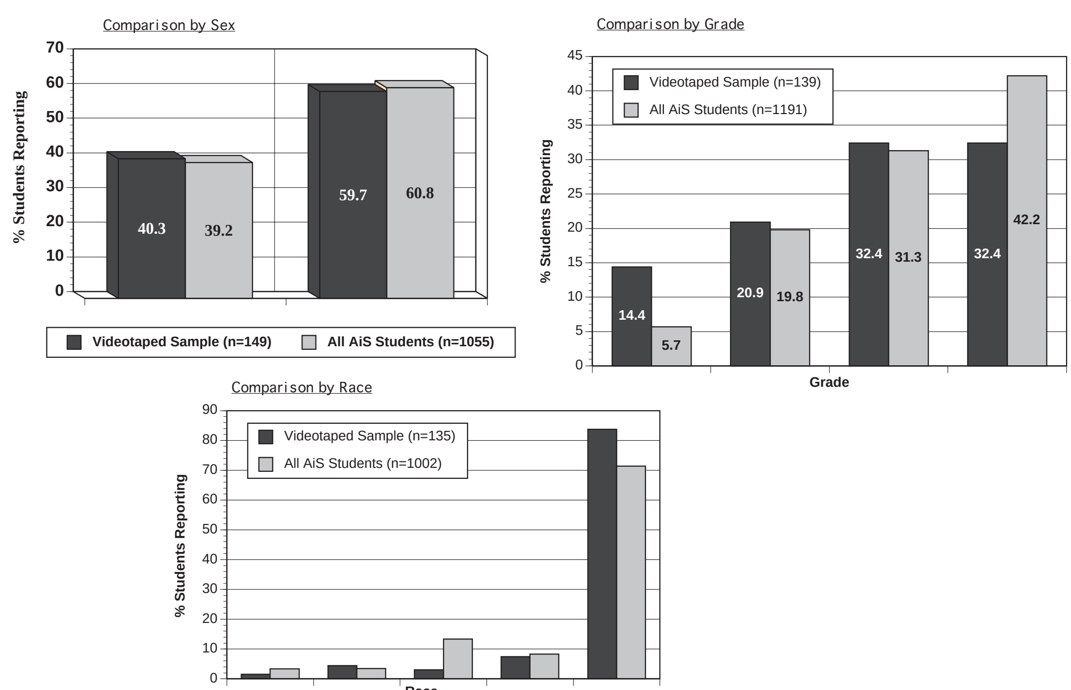
The centerpiece of the AiS evaluation focuses on student learning as evidenced in videotaped performances of students' final project presentations. A subset of students were required to present their final AiS projects to an audience of Department of Energy program staff, state site coordinators, and their teachers. Videotapes were scored on criteria developed at the Center for Children and Technology through an NSF-funded research project on the use of video as a tool for documenting students' performance-based assessments (Frederiksen, 1994a; Frederiksen, 1994b; Frederiksen, 1994c; Frederiksen & Collins, 1989; Hawkins, Bennett, & Collins, unpublished).

Two criteria were used to select the schools where videotaping was carried out: i. evaluation staff had conducted school site-visits; ii. the school had a dedicated AiS class (not a club or after-school enrichment program). Videotaping was carried out at fifteen schools, and a total of 67 projects were videotaped. A subset of 60 projects was selected for analysis.[11]

The final subset of students whose presentations were analyzed included 139 students. Demographically, the subset was quite similar to the AiS student population profile. The subset was 59.7% male, and 40.3% female. The racial distribution of the subset was slightly over-representative of Caucasian students (83.7%, compared to 71.4% of the full sample) and under-representative of Hispanic students (3% compared to 13.3% for the full sample). The sample was also 7.4% African American, 4.4% Asian, and 1.5% Native American (n=135) (see Figure 52).

Across most journal variables, there was minimal difference (less than five percentage points representing fewer than ten students) between responses from the whole group of students and the videotaped sample of students. The greatest difference occurred in responses to May self assessment questions: More students (11) in the whole group than in the videotaped sample indicated that they would like to alter time-management aspects of their projects.

Figure 52
Select Comparison of All AiS Students vs. Videotaped Sample



Response rates to journal questions tended to be about ten percentage points higher among the videotaped sample. For instance, in March, 118 students responded to questions about project difficulties and mentor interactions. These students represented 51% of the whole group, but 61% of the videotaped sample.

Procedures for Data Collection

To make the videotaping of students' project presentations an authentic and meaningful record of student learning two important steps were taken: i. students and teachers were informed about what would be expected of them; ii. questioners and videographers were trained.

Preparing students and teachers for the videotaped presentations. Preparation for the videotaping of students' projects began during the fall workshops, when presentations of the findings from the 1993-94 were made by evaluation team members, project coordinators, and/or teachers who had participated in the coding process. These presentations served to re-introduce the goals and objectives of the evaluation, the techniques of performance-based assessment, and the criteria that would be used to evaluate student performances.

During March the schools where the videotaping took place had been identified and teachers and students at those sites were prepared in more detail. Teachers at these schools were contacted by e-mail, and notified that videotaping would take place in their classrooms. The goals of this process were reviewed, and the format for the videotaping was outlined. A list of questions that students were expected to address in their presentations was also distributed. Teachers were encouraged to share the list with their students, and to help their students prepare for their presentations through rehearsals, mock videotaping, or discussions.

Training questioners and videographers. On March 17, 1995, representatives from each of the five states attended a training workshop at EDC offices in New York. The purpose of the workshop was to communicate a consistent structure to all participants which would make it possible for the videotaped performances to be consistent technically, structurally, and in content. Participants were also introduced to a set of mandatory questions that would be asked of all students included in the videotaping. These questions were developed in response to coder feedback from the 1993-94 evaluation, in order to increase uniformity of content across project presentations. Drawing on other research with videotaped assessments (Frederiksen, 1994a; Frederiksen, 1994b; Frederiksen, 1994c; Rochelle & Frederiksen, 1992), technical procedures, questioning strategies, and expected content of student presentations were reviewed. Questioners and videographers were provided with materials to support them in the taping process.

All taping and questioning was conducted by staff of the three Department of Energy laboratories. Finished tapes were sent to EDC offices.

Procedures for Analysis

Selecting and training coders. Performance-based assessments that are designed to authentically reflect the goals and objectives of a program require that judgments of students' performances be made by those who are most familiar with the program (McDaid & Davis, 1991; Rudner, 1992). In school-based projects those individuals are almost always teachers currently using the relevant curriculum. Accordingly, a decision was made during the 1993-94 evaluation to use AiS teachers to score students' project presentations.

Four of the six AiS teachers who had worked as scorers during the 1993-94 evaluation were able to participate in the coding process again this year (one teacher was no longer involved in the AiS program, and another had a fellowship at a Department of Energy laboratory that conflicted with the coding schedule). The two openings were filled by teachers from Alabama and Colorado, the states that were not involved in the evaluation during 1993-94. Scorers were solicited from Alabama and Colorado via e-mail sent by the state coordinators. Interested candidates were asked to notify EDC staff and to briefly describe their experience in the AiS program. Two new scorers were selected from four applicants.

Scorers participated in an intensive three-day training workshop at the EDC offices on June 27-30, 1995. Training focused on hands-on experience in using the coding scheme, and on discussion of teachers' developing understanding of the goals and structure of the coding scheme. Teachers worked in pairs, viewing tapes, discussing their responses to them, and determining together how to code them appropriately. Group discussions after each coding session focused on proper coding techniques, and the importance of citing concrete evidence for judgments. Group consensus was reached on codes for each of the tapes used in training.

Criteria for coding. The coding scheme is based on criteria developed for videotaped, performance-based assessments (Frederiksen, 1994a; Frederiksen, 1994b; Frederiksen, 1994c; Frederiksen & Collins, 1989; Hawkins, Bennett, & Collins, unpublished manuscript) developed at CCT. Over a period of several years CCT researchers have worked in collaboration with teams of teachers to develop and refine criteria that reflect students' capacities to understand content, think critically and analytically about it, communicate it well to others, and work collaboratively with their peers.

During the 1993-94 evaluation, this scheme was modified to reflect the aspects of student work most relevant to the goals of the AiS program, based on our knowledge of the AiS program, and preliminary viewings of a sample of project tapes, and pilot testing with researchers at the Center. For the 1994-95 evaluation, structural modifications were made to the criteria to increase coder reliability. These changes were made based on the results of the 1993-94 evaluation and feedback from the 1993-94 coders. The changes were not substantive but simply allowed coders to increase the uniformity of their work during the coding process.

The coding scheme includes five dimensions, each of which are coded on a scale of 1 to 5, with 1 representing poor work and 5 representing outstanding work. The five dimensions are:

- Understanding: To what extent do students demonstrate knowledge of their area of inquiry?

- Critical thinking: To what extent are students able to be reflective about the challenges and problems they encountered in their project and the larger implications of their work?

- Clarity and coherence of presentation: To what extent are students able to effectively communicate their ideas to others?

- Teamwork: To what extent do the students work collaboratively on substantive aspects of the project?

- Technical competence: To what extent are students able to apply programming skills to analyze or investigate their area of interest?

Procedures for coding. An identical coding scheme was used by all coders, for all project tapes (with the exception of teamwork codes, which were not applied to individual projects). Codes assigned to project groups were assigned to all individual students in that project group. All tapes were coded by two independent coders. Tapes were assigned to coders randomly.

One point discrepancies were resolved by averaging the codes (i.e., a score of 4 and a score of 5 became a 4.5), and 2 and 3 point discrepancies (i.e. scores of 2 and 4 or 2 and 5) were resolved by researchers, who examined coders' evidence statements, reviewed the project tape in question, and arbitrated a resolution (Frederiksen, 1994a).

Reliability. The overall reliability of the scores was 88%. This was calculated based on the number of pairs of scores that matched or were off by one degree. Of the remaining pairs of scores, 7% were off by two degrees, and 1% were off by three. Another 4% contained errors and were also resolved by the evaluation team. Relative to other research projects using similar assessment techniques, these scorers achieved an extremely high level of reliability (Frederiksen, 1994a).

Results

Students' scores on their videotaped performances were subjected to a cluster analysis. The goal of this analysis was to determine how students' scores could be grouped into clusters which would describe different types of most-typical performances, and then to determine what factors from the demographic and learning process data were significantly related to the distinctions among clusters of student performances.

Cluster analysis resulted in a three-cluster distribution of the 139 students.[12] Clusters were defined by determining those groupings which had maximally distinct means across the five dimensions of scoring. See Table 13 for an overview of cluster means.

Table 13

	Understand	Critical Thinking	Clarity	Teamwork	Technical
High Cluster (n=52)	4.69	4.47	4.41	4.85	4.22
Middle Cluster (n=49)	3.60	3.43	3.53	4.22	3.45
Low Cluster (n=38)	3.00	2.68	2.79	3.77	2.44

37% of the sample fell into the High Cluster. Their scores reflected very high marks across the five dimensions, and they scored particularly well in understanding and teamwork. 35% of the sample fell into the Middle Cluster. Scores for this cluster were very consistent across dimensions, with the exception of their relatively higher teamwork score. 27% of the sample was in Low Cluster. This cluster' was particularly low in technical competence (2.44), but exhibited a relatively higher teamwork score (3.77), in comparison with their scores on other dimensions.

Discussion

The three clusters share a similar profile of scores across the dimensions (see Figure 53). All three clusters exhibit relatively consistent scores across understanding, critical thinking, and clarity, a somewhat higher teamwork score, and a slightly lower technical competency score. However, the clusters are distinct from one another in the level of the scores they include: the High Cluster reflects scores predominantly in the above average to outstanding realm, the Middle Cluster reflects scores midway between average and above average, and the Low Cluster includes average to slightly below average scores. The following descriptions elaborate on the types of performances that corresponded to these mean scores.

High Cluster. 37% of students fell into this cluster (n=52), which includes 23 of the 60 projects evaluated. Scores for this cluster ranged from a high of 4.85 on teamwork to a low of 4.22 on technical competence. This cluster is very high-scoring across the dimensions, and is particularly distinct from the other clusters in the level of understanding (4.69) and critical thinking (4.47) indicated by the mean cluster scores.

A project in this cluster might be an investigation of the varying mortality rates for breast, lung and prostate cancers. During their investigation, these students began to research why different cancers grew at different rates, but abandoned this line of inquiry as they realized that the growth rate of the cancer had no impact on mortality rates, but only on durations of illnesses. Using mortality data for the last thirty years found on-line from the National Institute of Health and from the American Cancer Society, and comparing it with population projections collected from census data, students wrote a program that calculated the percentage of the population that could be expected to die from various types of cancer over the next thirty years. In establishing these predictions, students recognized that they needed to account for differences in cancer rates for males and females, and regional differences, and included these variables in their model.

The high understanding score for this cluster (4.69) suggests that these students had succeeded in defining a coherent area of inquiry and had mastered the content knowledge necessary to carry out an effective project. Critical thinking and clarity scores (4.47 and 4.41) for this cluster are high as well, though slightly lower than the understanding score. The slight drop in critical thinking suggests that students may not be completely fluent in describing *how* they thought about the problem they were addressing, even though they are clearly able to demonstrate that they understand the content of their project (indicated by factors such as being able to define terms and variables, being able to present a clear problem statement, etc.). These students' presentations were also well structured, covering the crucial elements of the project – initial questions, techniques of inquiry, findings, and implications – in a clear and sensical fashion.

The very high teamwork score in this cluster indicates that for presentations included in this cluster, students succeeded in doing three things: identifying all team members as making substantive contributions to the project; including all team members in substantive aspects of the presentation; and allowing all team members to answer questions.

The technical competency score for this cluster is lower than their other scores, but is still strong (4.11). This score had a larger standard deviation (0.66) than most of the mean scores, indicating a relatively broad range of individual project scores. Students in this cluster were typically able to outline the function and structure of their program, and to provide some general explanation of the role the program played in their project. In many cases students' programs modeled the interaction of more than two variables, and in most cases students wrote all or most of the program themselves.

High scores in understanding and critical thinking dimensions suggest that projects in this cluster are driven by students' high level of mastery of content knowledge and relevant conceptual issues, while allowing for variation in students' programming skills. Students in this cluster succeeded in defining a tractable problem, developing an adequate understanding of the relevant content material, creating a program that supported a well-defined part of their inquiry, and interpreting their findings appropriately. These students succeeded in *integrating* their understanding of their topic and their knowledge of programming to create a well-defined investigation.

Middle Cluster. 35% of students fell into this cluster (n=49), which includes 20 of the 60 projects evaluated. With the exception of the high teamwork score (4.22), mean scores for this cluster were all very similar, falling within a 0.17 range of one another (between a low of 3.43 on critical thinking, and a high of 3.60 on understanding).

A project in this cluster might be similar to one groups' analysis of whale communication. These students were interested in calculating how far apart two whales could be and still be able to communicate with one another. They began by doing content research to determine the key factors that would affect the flow of sound waves through water. They determined that these factors were the depth of the water, the salinity of the water, the pitch of the sound produced by the whale, and the speed and direction of the whales' movement. The students acquired, from a mentor, a formula that described the interaction of these variables. They then created a program that executed the formula and reported the strength of the sound waves at particular distances, given varying levels of the relevant variables. At this point the students realized that they did not know how to make a judgment, based on these decibel levels, about whether or not a whole would be able to hear a tone. Instead, they created an arbitrary cut-off point that would represent inaudibility. In addition, although these students managed to create a program that manipulated a set of variables, they had a limited conceptual understanding of how and why those variables interacted in the way that they did. Finally, they did not exploit the capacity of their program help them learn more about the interactions by varying values systematically within the program.

Scores for understanding, critical thinking, clarity and technical competence for this cluster all reflect work that fulfilled many program expectations, but left crucial gaps in the structure, methods, or reasoning behind the project work. These scores suggest that students were able to present a coherent explanation of their work, but that they did not have the depth of understanding that was exhibited by students in the High Cluster. For example, the understanding score of 3.60 and the critical thinking score of 3.43 suggest that students in this cluster typically were able to identify and describe the topic of their research, but may not have provided a full explanation of why they had used specific methods of inquiry. Similarly, groups in this cluster were likely to provide accurate descriptions or identifications of visual displays included in their project, but were limited in their ability to extrapolate further knowledge from their own graphs, or to generalize about the relationship among variables described by their graphs or visualizations. Components of the project – hypotheses, methods, findings, conclusions – were typically identified, but not presented in a complete or coherent order. The programming involved in this cluster was most likely to be either a program that executed a single well-defined function, which the students were able to identify and describe, or a more complex program which students were not fully able to describe or to integrate with their understanding of other project components (mean score=3.45).

The teamwork score for this cluster is high (4.22) but also has a large range (standard deviation=.95), indicating that this cluster includes groups with a range of levels of teamwork. Students in this cluster may have worked well together, sharing substantive responsibility for project development and participating equally in the presentation of the work. Or they may have performed less well, allowing one or two members of the group to dominate either the project work, the project presentation, or both.

Students in this cluster addressed identifiable problems and were able to describe, to some extent, the strategies they used in their investigation. Projects in this cluster, though, typically exhibited *gaps* in understanding that indicated that students' engagement with their topic was limited in some way. Some of these students addressed substantive content areas, but limited themselves to investigating *closed-ended* problems; these students created projects that demonstrated already-known functions or phenomena. Other students in this cluster addressed more open-ended questions, but had difficulty in presenting a fully integrated explanation of their work. Projects in this cluster were coherent in their initial presentation, but in questioning, students were only able to offer rote or limited explanations of key sections of their project, such as relationships between the content of the project and the programming involved, choices they made in defining their topic, or the interactions of the variables under study.

Low Cluster. This is the smallest cluster, including 27% of students (n=38), and 17 of the 60 projects evaluated. Mean scores ranged from a low of 2.44 on technical, to 3.77 on teamwork. The gap between the low and medium clusters is narrow on teamwork (3.77 compared to 4.22) and widest on critical thinking (2.68 compared to 3.43) and technical competence (2.44 compared to 3.45).

A project in this cluster might involve students who wanted to predict where a bomb dropped from a plane would fall, given its initial altitude, velocity, and location relative to the ground. These students used the gravity constant to calculate the time it would take for a bomb to reach the ground, but were not able to determine how the plane's velocity and initial location, or other variables (such as air resistance) would affect the path of the bomb's fall. Consequently, their findings did not correspond to their initial questions, as they focused on reporting time as a function of altitude, rather than describing the curvilinear path a dropped bomb would actually follow. These students' initial intuitions about the path of the bomb were, in this case, more complex than the model they were able to generate in their actual project; this is indicative of the difficulties students can face as they attempt to derive formulae that reflect the phenomena they are interested in studying.

Mean scores for this cluster suggest that students typically were able to state a coherent research question, and to identify pieces of the project such as the variables involved or equations used, but that the larger functional relationship between the conceptual content of their work and the process they had undertaken was fundamentally incomplete or unclear. An average understanding score (3.00), reflecting students' ability to identify but not integrate the various components of and ideas behind their work, is further complicated by a lower critical thinking score (2.68). This score reflects students' difficulty in connecting their work strategies with the questions driving their inquiry. Strategies for problem-solving in this cluster were sometimes dictated by a mentor, or were derived from a book.

The teamwork score for this cluster suggests that typically these groups were dominated by one or two members, either in the distribution of tasks or in the presentation, or both. The technical competence score (2.44) indicates that this cluster includes students who did write programs as a part of their project work, but who were unable to provide a complete or clear explanation of the structure and function of the program, or of its relation to the content of the project.

Students in the Low Cluster are lacking an understanding of how the content of their project relates to the mathematical components of their work. This connection may be stated vaguely, it may be incorrectly stated, or it may simply not be included in the presentation. These students typically focused on isolated pieces of content material and/or programming functions, and lacked a unifying process of inquiry or a guiding set of questions that would focus their work. The students in this cluster exhibit the most difficulty with creating a well-conceptualized and executed program. Their difficulties with the programming component of the course lie in two areas: understanding how the program functions, and understanding how the mathematical functions carried out by the computer (as opposed to simply the values produced) relate to the conceptual basis of their project.

Factors Influencing Student Performance

In order to determine those factors which were significantly related to students being represented in a particular cluster, demographic and process learning data were analyzed to determine which variables were significantly correlated with each cluster.

Method

ANOVAs were run to isolate those variables which were significant in relation to the clusters.[13] Correlation coefficients were run to determine exactly which values of the variables correlated with the clusters. Significance levels ($p<.05$) for Pearson's correlation coefficients are reported here.

Results

High Cluster. Students in this cluster were most likely to be working with highly experienced teachers (more than twenty years as educators) ($p<.0005$), and were least likely to be working with inexperienced teachers (less than ten years) ($p<.05$). Teachers of students in this category were most likely to frequently use project work in other classes that they teach ($p<.05$). These students' teachers were also most likely to be highly experienced users of educational technology (ten or more years, $p<.0005$), and were also most likely to have modems at home ($p<.05$).

Students in this cluster are likely to have a high level of previous knowledge of programming ($p<.005$); that is, they are likely to have reported familiarity with at least three programming languages. Students' whose project topic was computer science-related were likely to be included in this category (p=.058). These students also are likely to have both a computer and a modem at home (p<.05), and to have reported in their September journals that they were expecting to do research as a part of AiS (p<.05).

Middle Cluster. These students were most likely to have teachers with less than ten years of teaching experience (p<.05). They were also most likely to have teachers with few years of experience with educational technology, and least likely to have teachers with ten or more years of experience with educational technology (negative correlation).

Low Cluster. Students in this cluster were not likely to have highly experienced teachers (negative correlation, p<.005). They were most likely to have questions about programming in the middle of the school year, according to their journal responses (p<.05). Also, projects that focused on physics problems were most likely to be included in this cluster (p<.05).

Discussion

The significant variables describe a set of circumstances that are particularly important to the quality of student outcomes. Contextual data collected through site visits and teacher interviews provides a basis for informed conjecture about connections between the significant variables and students' performance in AiS.

- Teacher experience. AiS teachers need to be able to balance many different tasks to create a successful AiS classroom: teaching specific skills, supervising original research, guiding students through a long-term process of project development, finding and coordinating mentors for students, assessing complex work, etc. The more expertise they have available to draw on as teachers, and the less they are impeded by lack of familiarity with the technological tools at hand, the more successful they can be in supporting students in creating successful AiS projects. The following aspects of teacher's experience all had a significant impact on student outcomes this year:
  - *Teachers' years of teaching experience*. The most experienced teachers were most successful in supporting students in their project work. Teachers frequently describe one of the challenges of AiS as being the complexity of the work students are expected to do; experienced teachers have many more years of practice in supporting students' work on diverse and complicated tasks.
  - *Teachers' degree of experience with using project work in the classroom*. Familiarity with managing project work in the classroom also had an impact on teachers' ability to support successful student work. This variable was not related to teachers' years of experience in the program, or to their amount of teaching experience – regardless of these variables, teachers who are making project-based student work a major part of their everyday teaching practices are able to draw upon these skills to support the project work students do in AiS.
  - *Teachers' years of experience working with educational technology*. Teachers who are experienced users of educational technology are also successful in supporting students' AiS work. These teachers may face fewer technical challenges in the day-to-day teaching of AiS, freeing them up to spend their time on more substantive aspects of the program. Additionally,

they may be able to think more broadly than other teachers about how the technological tools available can support their students' work.

- *Whether teachers have modems at home*. Having a modem at home is an indicator that teachers have access to resources from home that allow them to spend additional time on tasks like developing their own skills with the technology, preparing for classes, or communicating with colleagues. Being able to devote extra time to this kind of work has a significant impact on the quality of student outcomes.

- Student programming knowledge. Students with a high level of programming knowledge previous to their involvement in AiS are more likely than students without that background to be in the High Cluster. This cluster does include other students, and while programming knowledge is not a necessary prerequisite to doing well in AiS, it does confer advantage on students who have this kind of knowledge. Students who have this level of previous knowledge are most likely able to learn FORTRAN more easily than other students, as they are accustomed to the structures and logic behind programming. Students with this kind of background can be encouraged to serve an important role in AiS classrooms, by acting as formal or informal mentors and advisors to other students.

- Student modem at home. Access to a modem at home provides students with additional time for research and communication. Students who can bring all aspects of their work, including those carried out on the computer, beyond the confines of their daily classtime, have more opportunities to expand their research and explore new resources, activities that are likely to have a positive impact on the eventual shape of their final project.

- Project topic. Some project topic areas were significantly more successful than others this year. This finding is most likely related to a number of other factors, including the types of resources that are most readily available to students, the goodness of fit of some topics to computational methods of solution, and the availability of mentors in some topic areas. Physics projects were least likely to do well, and this finding no doubt reflects a number of different influencing factors. AiS students are not bringing a high level of science background to the course; most students involved in physics projects in AiS have never taken physics before. Many physics projects were also poorly designed, as students intended to investigate a particular topic but were not able to define a focused question to guide their work. Finally, many of projects which were built around highly focused "cookbook" problems assigned by teachers or mentors were physics problems, and many of these projects were not successful because students typically had little understanding of the subject matter involved in these types of projects.

  Computer science projects were most successful this year. There is reason to conclude that this finding is connected to the fact that students with a great deal of programming background previous to their participation in AiS are likely to do well in the course. These projects are typically developed by groups in which some or all students are experienced programmers. They are able to define a project that is centered around the sophistication of their programming skills, and produce projects that successfully build on their strengths.

- Students expecting to do research. Students who began the course knowing that research was part of the AiS curriculum When students understand research to be a part of AiS from the beginning of their involvement with the class, they are likely to begin taking on that line of work earlier in the year. Combining research into their topic area with the programming they are likely to be learning early in the year is likely to provide them with a head start

- Students having questions about programming in February. This variable is significant but reflects a small number of students. We hypothesize that these were students who were still focused on very basic programming issues late in the school year, and who did not produce strong projects because they were not able to make effective use of programming as a part of their investigation.

Comparisons to 1993-94 Findings

The 1994-1995 evaluation of Adventures in Supercomputing was designed to expand upon evaluation work conducted during the 1993-1994 school year. In 1993-1994, evaluators worked with nineteen schools, all in their second year in the program, and representing three states (Iowa, New Mexico and Tennessee). Demographics, contextual information, and videotaped student performances were all used to determine the types of experiences students were having in AiS, and those factors which were most prominently supporting or impeding their work. This year, the evaluation team used the same research design to study second year schools in Alabama and Colorado.[14] Additionally, eight third-year AiS schools in Iowa, New Mexico and Tennessee were included in the sample. This selection allowed us to pursue two goals: to establish a uniform body of evaluation data collected from second-year AiS schools in all five participating AiS states; and to continue to evaluate the development of the program in schools undertaking their third year in AiS.

The clusters of student work identified in the previous year's evaluation (1993-1994) were distinct from one another both in the *level* of their scores and in their *profiles* across the five scoring dimensions (see Figures 54 and 55 and Table 14). The *Integrated Knowledge* cluster was the highest scoring cluster in this group. The students in this cluster exhibited high scores across all five dimensions, but their understanding score was particularly high. These students succeeded in combining a substantive body of knowledge about the subject matter of their project with a real understanding of the methods of inquiry they had used to investigate the questions or problems at the center of their project. The *Procedural Knowledge* cluster had average to above-average scores. Their scores were relatively consistent across the dimensions except for a distinct drop in the technical competence dimension. These students typically had executed all the steps necessary to creating a computational science project, but they did not have a good understandings of the programs they had written, and consequently had a difficult time explaining how the mathematical model they were using helped them to address or solve specific questions or problems. Finally, the *Fragmented Knowledge* cluster had average to below-average scores, and their scores varied the most across the dimensions. This was the only cluster that had an understanding score that was lower than their critical thinking score; additionally, they had very low technical scores. This cluster included projects that were not securely grounded in any clear hypothesis or problem statement. Students in this cluster had not been able to gain a substantive understanding of either the content or the mathematical and programming components of their project.

Like last year, the full pool of scored projects were separated into three distinct clusters with well-separated score profiles. However, the 1994-1995 clusters show some interesting changes when compared to last year's sample. Four key points lie behind the main differences between the 1993-94 and the 194-95 clusters:

- Overall, mean scores for student projects are *higher this year* than scores for last year's sample in four of the five scoring dimensions (all except critical thinking, which is almost identical to last year). Consequently, mean scores for the three clusters are also higher than last year's mean cluster scores. In other words, while there is a highest-scoring cluster in both the 1993-1994 sample and the

1994-1995 sample, this year's high-scoring group centers around a higher set of means than last year's. This is true for the middle and low clusters as well.

- The profiles of the three 1994-95 clusters are *almost identical* across the five scoring dimensions. Unlike the 1993-94 clusters, which had different profiles (Integrated, Procedural, and Fragmented) in addition to different scoring levels, the 1994-95 clusters are primarily distinguished by their scoring levels (High, Medium and Low). Relative strengths and weaknesses across the five scoring dimensions are consistent across the clusters this year – that is, students in all three clusters had consistent scores across understanding, critical thinking and clarity, relatively higher teamwork scores, and slightly lower technical competence scores. Last year students were not only performing at different levels, but in very different ways that could be described by the distinct categories; this year, students are not so much performing in different *ways* as they are performing at different *levels* of achievement.

- There are *fewer significant variables* associated with student outcomes this year. Across all of the information collected about the students, teachers and schools involved in AiS, a very small group of variables were found to have a systematic and persistent influence on student outcomes this year.

- Students are *more evenly distributed* across the clusters this year; 37% of students are in the High Cluster, 35% in the Middle Cluster, and 27% in the Low Cluster. Last year just over half (51%) of the sample was in the Integrated Knowledge cluster (which was the highest scoring); 34% was in the middle, Procedural Knowledge cluster, and 15% was in the lowest, Fragmented Knowledge cluster.

Taken together, these changes in our cluster findings suggest that rather than describing three distinctly different types of project work, as they did in 1993-1994, the 1994-1995 clusters represent a different kind of trend. The findings suggest that the project work described by this year's clusters is essentially all on the same continuum, and that the three clusters simply represent different levels of performance on that shared continuum.

This change in the character of the clusters, coupled with a decrease in the number of other significant variables, suggests that teachers and students in AiS are gaining a clearer and more substantive understanding of what constitutes a successful AiS computational science project. As teachers continue to become more familiar with the curriculum and adapt it to their strengths and interests, and as the course becomes a familiar part of the available curricula in participating schools, teachers and students will continue to build, based on experience and growing expertise, a more fully developed understanding of the elements that are necessary to good computational science research.

Changes in teamwork and technical competence scores between 1993-94 and 1994-95 particularly support this inference. The largest growth in mean overall score from last year to this year was in teamwork (Δ=0.48). Additionally, size of project group and sex mix in project group were both significant variables for student outcomes last year and are not this year. Also, a number of students reported in their first journal responses that they expected teamwork to be a part of AiS (a response that we did not receive in 1993-94). All of these findings are convincing evidence that teamwork and group projects are central to the AiS program, and that increased emphasis by teachers and program coordinators on supporting these teaching methods has had positive results. Teamwork has been stressed in on-going AiS teacher workshops in many of the states last year, both as a result of last year's evaluation recommendations and because teachers were aware that this was a difficult and important part of AiS.

Technical scores also rose between 1993-94 and 1994-95 (Δ=0.27). This rise is largely accounted for by the fact that almost all student projects evaluated this year included some amount of programming. Consequently, the technical competence scores at the low end of the scale are more moderate than last year. While students continue to be capable of creating strong AiS projects without advanced programming skills, the appropriation of some kind of mathematical model and the translation of that model into a functioning program has become more uniformly accepted as central to AiS project work.

Table 14

1993-1994 Clusters

	Understand	Critical Thinking	Clarity	Teamwork	Technical
Integrated knowledge (n=70)	4.62	4.21	4.04	4.30	4.23
Procedural knowledge (n=47)	3.24	3.35	3.39	3.52	2.76
Fragmented knowledge (n=20)	2.18	2.88	2.45	2.72	1.30

Conclusions

The goal of this evaluation was to determine what types of learning experiences were typical of students participating in the AiS program. In order to answer this question three types of data were collected and analyzed: demographic data describing the participating students, teachers and schools; contextual data describing the particular circumstances in which the AiS curriculum is implemented; and student learning data documenting the process and the outcomes of students' work. The data documenting student learning outcomes — videotapes of student groups presenting their projects and being questioned about them — was analyzed according to performance criteria. Students were then clustered according to the scores they received on their presentations. There were found to be three resulting clusters (High, Medium, Low) which were distinct from one another in the quality of student performance on the five dimensions of the performance criteria: understanding, critical thinking, clarity, teamwork, and technical competence. Clusters were then analyzed in relation to the demographic data and learning process data to isolate the variables that significantly correlated with membership in each cluster. Contextual data was used to aid in the interpretation of the significant variables.

Overall, three clusters of student achievement were identified that exhibited similar profiles, but whose mean scores centered around different points on the 1-5 (poor to outstanding) scale. Each of the three clusters had consistent scores across understanding, critical thinking, and clarity; a relatively higher score on teamwork; and a relatively lower score on technical competence. The High Cluster (37%) had very high scores across the dimensions, with a nearly perfect teamwork score and very strong scores for understanding, critical thinking and clarity. These scores reflect students' ability to define a tractable problem for investigation, use computational techniques effectively in their work, and understand the relationship between the content and the techniques of their inquiry. The Middle Cluster (35%) had consistently above-average scores, but was less successful in fully integrating their project work. Students in this cluster were often successful in defining and completing a piece of work, but their ability to conjecture based on their knowledge, to extract further information or ideas from their findings, or to grasp the implications of their work, was limited. The Low Cluster (27%), the smallest of the three, included students who, most often, were unable to create a well-defined project. Their presentations were often diffuse and provided little evidence that they had a clear sense of what they had set out to find or determine, or that they were able to make sense of the results of their work.

The following conclusions can be drawn from this analysis:

- Mean scores for the sample of students whose presentations were videotaped and analyzed are higher than scores for last year's sample, suggesting that student performance in AiS is becoming stronger.

- The increase in uniformity of the profiles of the clusters, and increased uniformity of distribution across the clusters, indicates that across the clusters students are addressing similar issues and challenges. While students are producing work of varying completeness and quality, the evidence suggests that rather than distinguishing students who faced distinctly different kinds of obstacles and challenges in the class, the clusters describe a continuum of student performance encompassing stronger and weaker performances in similar contexts.

- A specific group of teacher variables are strong indicators of student performance in AiS. Teachers' ability to support successful project work is strongest when they have a great deal of previous teaching experience (more than twenty years), experience with using educational technologies, experience with guiding students in project work, and access to computers and modems at home.

- AiS students are bringing strong mathematics backgrounds to the course but minimal science background. Over half of the students begin the course with some prior experience with programming. Those students with a high level of previous programming experience are significantly more likely than other students to perform well in our assessment. Their level of math background has some impact on performance (student with more math performing more strongly), while science background has no impact on performance.

- AiS is reaching a range of students, of both genders, from different racial, ethnic and socio-economic backgrounds. These factors do not play a role in predicting student success in the program.

- There are a number of findings that suggest that students with higher levels of experience with technology and with more previous programming knowledge are more likely than others to do well in AiS. Although no significant correlation was found linking student sex to level of achievement in the program, other evidence suggests that male students are consistently more likely to have the higher levels of experience with technology and programming that can provide important support for successful work in AiS.

a) Male students in AiS have a small but persistent lead on female students in their general level of exposure to and experience with technology. This includes how frequently they report using technology for schoolwork, the number of software applications they report being able to use, and the number of programming languages they know before taking AiS.

b) In journal responses, female students reported more frequently than male students that they had trouble with the programming components of the course.

c) Computer science projects were very likely to do well this year, and 15 of the 16 students who worked on computer science projects that were in the High Cluster were boys.

d) 13 students in the videotaped sample (N=139) were rated as "highly experienced" programmers before they took AiS. Twelve of these students were boys, and twelve of the thirteen were in the High Cluster.

These findings suggest that while there are multiple pathways to success in AiS, one of those pathways is through sophisticated programming ability, and intrinsic interest in exploring the technologies at hand. The data suggest that these skills and interests are predominantly held by the boys in the program.

- Selecting and framing viable, computationally-focused projects continues to be the central challenge of this program for students and teachers alike. Teachers expressed strongly, in site visits and surveys, that they are continuing to struggle to find ways to integrate programming into their students' interests, and students often adapt or entirely alter their projects in order to make them adequately computational in nature. The broad range of strategies teachers and students invent to respond to this difficulty is apparent in site visit records, videotaped student presentations, and the results of the videotape analysis. Teachers' and students' project development strategies reflect a continuing uncertainty about how to apply computational techniques to questions at hand. Although teachers and students are aware of the kinds of methods and approaches that are appropriate to computational science, bridging the gap between an abstract understanding of these methods and their practical application in relation to specific problems or questions remains problematic for many AiS classrooms.

- Mentors are playing a range of roles in student projects. In some cases they are central to the students' work and support them in inquiries that are beyond the skills or resources of the classroom teacher; in some cases they are a negative force, discouraging students from pursuing one topic in favor of another which may not be to the students' liking or interest. In surveys, journals, and discussions during site visits, teachers and students spoke frequently about the important role played by the mentor, or by the lack of a mentor. Finding mentors continues to be difficult and time-consuming for many teachers, and the program lacks a systematic structure to support this process. Finally, teachers and students have distinct views of what the purpose of a mentor is — teachers emphasize the mentor as someone who should help to develop and refine the project topic, while students look to mentors to provide content information or help with programming.

- Time restrictions continue to constrain teachers in their efforts to fully implement the AiS curriculum. Like any innovative and technology-rich curriculum, AiS requires a great deal of time both to prepare for and to teach. Most AiS teachers report, both in surveys and during site visits, that they do not have adequate time available to pursue their own professional development in relation to this discipline, and to support their students' work. These constraints influence, in turn, teachers' ability to help students construct viable, well-constructed project work.

Recommendations

Many of the recommendations made here are based, in part, on our observations of efforts already underway in AiS classrooms. Many AiS teachers are findings creative solutions to challenges they have found in teaching AiS, and are building on new knowledge and new skills they have gained through the program.

Based on the evaluation findings, the following recommendations can be made:

- *Creating structures that will help students move from their own general interests to a focused hypothesis early in the year is key to the development of successful AiS projects*. Defining and carrying out projects that lend themselves effectively to computational techniques of inquiry continues to be a challenge for many students in the AiS program. Several states have taken steps to address this issue by bringing students in contact with experts early in the year to help students review their project topics. Another strategy would involve teachers during the summer workshops in critiquing both strong and weak AiS projects. Teachers could be asked to identify the project's strengths and weaknesses and could generate additional ways in which the students could be guided and supported in project work.

- *Data from the site visits strongly suggest that students need help in refining all of their research skills, particularly those associated with using the World Wide Web*. Once students have defined a topic it is often difficult for them to find appropriate information resources. Students who understand that research is central to their project work and who are able to make judgments about the quality and applicability of information resources tend to outperform those who do not. Prior to undertaking research, students need to work with their teachers to address the following sorts of questions:
  - What do think you need to know?
  - What kind of information would help you to answer your questions?
  - Where do you think you will locate appropriate information?
  - What are the key words that you will help you in an on-line search?
  - How will you evaluate the usefulness and applicability of the information?

- *We recommend that in all AiS classrooms, early on in the semester students begin to practice the process of identifying relevant variables, describing the relationship between the variables, building a mathematical models and flowcharting program functions.* The relationships between project work and programming continues to be difficult for many students. How to apply computational strategies to meaningful problems tends to be interpreted differently in different classrooms. In the most successful projects students are able to extrapolate the relevant variables from the problem they are trying to solve and build a conceptual model that then enables them to understand possible relationships between the variables. It is this process that enables them to take the next step of building a mathematical model that informs the design and development of their computational strategies.

When students spend time practicing the process of mathematical modeling, they gain experience that will help them to *derive* an appropriate program from the interactions they are studying. Ideally, this would be done by providing students with small-scale problems that can be solved by teams of students within one or two days. The advantage of this approach is that students are learning programming skills while constructing an understanding of the methods and procedures of computational science.

- *We recommend that in collaboration with AiS teachers, the coordinators develop a two to three page introductory letter and guidelines that AiS teachers and their students could share with potential mentors.* Identifying mentors that can help both teachers and students continues to be a challenge. Teachers need help in supporting students in the refinement and development of their projects, and students need support in developing effective computational strategies. To be effective, mentors need to be clear about what the scope and depth of their responsibilities are. An introductory set of guidelines for mentors should state the goals and objectives of AiS student projects, describe the ways in which mentors can assist students, mention the things mentors should try to avoid doing (e.g., solving the problem for students) and discuss realistic time commitment mentors should expect to make. In addition, to assist teachers in the identification and selection of mentors, the AiS program should begin to build a central database of individuals willing to participate in the AiS program.

- *Efforts need to be made to support those students who bring minimal experience with computers and/or with programming to AiS.* This can be directly addressed by teachers by teaming these students with students who have more programming background or experience using computers, whenever possible. Additionally, these students most particularly need to be helped to identify manageable projects that can be deeply addressed without requiring elaborate programming skills.

- *The program needs to continue to create opportunities for teachers with less experience in these areas to draw on the expertise of their colleagues.* Teachers' prior experience with project based work, coupled with their experience with using technology in the classroom have a strong impact on students' ability to carry out successful AiS projects. During summer institutes, efforts need to be made consistently to partner teachers who have different levels of experience with project work and with educational technology. Additionally, the states may want to encourage mentoring or coaching partnerships between schools, focused on maximizing all teachers' opportunities to continue learning from one another and sharing strategies for teaching and learning with technology.

Endnotes

[1] This section repeats the description of the AiS program presented in the 1993-1994 evaluation report. This was done so that this report could be distributed on its own to interested parties who may not have read the 1993-1994 report. Program descriptions and details of the evaluation design have been updated as appropriate. The 1993-94 report can be obtained from Education Development Center, Center for Children & Technology, 96 Morton St., New York, NY 10014, or from the AiS webpage: http://www.ornl.gov/olc/AiS/AiS.html.

[2] For example, 76% of twelfth graders reported that their science teachers lectured during classtime at least several times a week (NCES, 1991, in NSB, 1993).

[3] For purposes of comparison, all demographic surveys were designed to be consistent with demographic surveys conducted by the National Center for Education Statistics.

[4] This question referred to students' general computer use, not specifically to AiS.

[5] Data on number of students with knowledge of FORTRAN is not included here because the data suggest that students were including first exposure to FORTRAN in this year's AiS class as "knowing" the language, while the question was intended to elicit information on experience with languages prior to AiS.

[6] Percentages cited here are proportions of those students who reported taking any math or science classes at all.

[7] National statistics reported here reflect only courses taken during grades 9-12. Since some students are likely to have taken algebra I and II in junior high, the national norms for those courses are likely to be somewhat higher than those presented here.

[8] Teachers were asked to rank their top three choices, in order, for this question and the following questions which are reported in tables. Overall rankings for each item were computed by assigning the item three points for every number one ranking it received, two points for every number two ranking, and one point for every number three ranking.

[9] Journal questions were sent to teachers and students in semester-long classes every two weeks.

[10] Classes involved in AiS journalling include: East Limestone School, Andalusia High and Selma High School in Alabama; Gunnison High, Platte Canyon High , and George Washington High School in Colorado; North Polk High and West Bend-Mallard High School in Iowa; Albuquerque High, Estancia High, and Moriarty High School in New Mexico; and Giles County High, Horace Maynard High, and Southside High School in Tennessee.

[11] The 60 tapes were selected by eliminating tapes representing the work of students for whom we had no contextual data, and randomly eliminating tapes from over-represented schools.

[12] Three projects were eliminated from the sample at this point as outliers. These three projects had significantly lower scores across all dimensions than other projects, and could not be integrated into the cluster analysis without skewing the sample. In these cases, single students reported on work that had been done by a large team, and project topics were ill-defined and had been decided on late in the year.

[13] Independent variables run against the clusters were divided into two categories: those that were shared by members of any particular group (i.e., project topic, teacher variables) and those that varied on a student-by-student basis (mathematics background, sex). Variables of the first type were run against all of the projects in this sample; variables of the second type were run against the individual students in the sample. This approach eliminated spurious significances that would have appeared if all variables had been run on the individual student level.

[14] Alabama and Colorado began participating in AiS in 1993, and consequently their teaching cohort is a year less experienced than teachers in Iowa, New Mexico and Tennessee.

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